

# **Evaluation of Advanced Petroleum-Based Fuels**

**INTERIM REPORT  
TFLRF No. 356**

by

**W. E. Likos**

**U.S. Army TARDEC Fuels and Lubricants Research Facility  
Southwest Research Institute  
San Antonio, TX 78228-0510**

Under Contract to

**U.S. Army TARDEC  
Petroleum and Water Business Area  
Warren, MI 48397-5000**

for

**U. S. Department of Energy  
Office of Transportation Technologies  
1000 Independence Avenue, SW  
Washington, D. C. 20585**

Contract Nos.

**DAAE-07-99-C-L053 (WD03 of SwRI Project No. 03-3227)  
DAAK-70-92-C-0059 (WD69 of SwRI Project No. 03-5137)**

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**August 2001**

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E. C. Owens, Director  
U.S. Army TARDEC Fuels and Lubricants  
Research Facility (SwRI)

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13. ABSTRACT (Maximum 200 words) The U.S. Department of Energy, with the cooperation of DaimlerChrysler, undertook a series of evaluations of diesel fuel formulation alternatives using the newly released Daimler-Benz OM 611 diesel engine as a surrogate for an advanced diesel engine as identified by Partnership for the Next Generation of Vehicles (PNGV) program. The first phase, completed in 1998 (SAE 2000-01-2048), evaluated exhaust emissions and fuel economy benefits of several alternative diesel fuels without adjusting the engine control system. That work found that large reductions in engine out particulate emissions were possible with some fuels. In particular, compared to the 49 state on-highway diesel fuel used as a reference, a diesel fuel from the Fischer-Tropsch process, and a fuel consisting of a blend of dimethoxymethane and a Swedish Class 1 City Fuel-like petroleum fraction each reduced particulates on the order of fifty percent without increasing oxides of nitrogen emissions. This phase II work evaluated a subset of the seven fuels tested in Phase I, as well as fuels recommended by the Auto/Energy Ad Hoc Fuels Research Group, with limited optimization of the DaimlerChrysler OM 611 engine for each fuel. Because the fuels under consideration have differing physical and chemical properties, a portion of any change in exhaust emissions measured in Phase I may be due to the response of the engine's fuel injection system to differences in the fuel's physical properties. The approach for Phase II was to recalibrate several of the engine operating parameters that influence engine emissions and fuel economy for each fuel. The operating parameters considered in this optimization process included boost level, exhaust gas recirculation (EGR), fuel injection timing, and pressure in the common rail injection system. Engine-out emissions (no after-treatment) and performance were determined at a series of steady state test modes.			
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## EXECUTIVE SUMMARY

The U.S. Department of Energy, with the cooperation of DaimlerChrysler, undertook a series of evaluations of alternative diesel fuel formulation using the newly released Daimler-Benz OM 611 diesel engine as a surrogate for an advanced diesel engine as identified by the Partnership for the Next Generation of Vehicles (PNGV) program. The first phase of this program, completed in 1998 (1), evaluated the exhaust emissions and fuel economy benefits of several alternative diesel fuels without making any adjustments to the engine control system. That work found that large reductions in engine-out particulate emissions were possible with some fuels. In particular, compared to the 49 state on-highway diesel fuel used as a reference, a diesel fuel from the Fischer-Tropsch process, and a fuel consisting of a blend of dimethoxymethane and a Swedish Class 1 City Fuel-like petroleum fraction each reduced particulates on the order of fifty percent without increasing oxides of nitrogen emissions.

This phase II work evaluated a subset of the seven fuels that were tested in Phase I, as well as fuels recommended by the Auto/Energy Ad Hoc Fuels Research Group, with limited optimization of the DaimlerChrysler OM 611 engine for each of the fuels. Because the fuels under consideration have differing physical and chemical properties, a portion of any change in exhaust emissions measured in Phase I may be due to the response of the engine's fuel injection system to differences in the fuel's physical properties. The approach for Phase II was to recalibrate several of the engine operating parameters that influence engine emissions and fuel economy for each fuel. The operating parameters considered in this optimization process included boost level, exhaust gas recirculation (EGR), fuel injection timing, and pressure in the common rail injection system. Engine-out emissions (no after-treatment) and performance were determined at a series of steady-state test modes.

These results illustrate both the impact of engine control strategy on engine-out emissions, and the substantial impacts that changes in fuel formulation can have on engine-out particulate emissions. The results with ALS and ADMM15 indicate that the reduction in particulate, at least with oxygenated fuels, can allow increased levels of EGR in order to reduce the engine-out NOx emissions.

## **FOREWORD/ACKNOWLEDGMENTS**

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The author would like to acknowledge the assistance provided by Messrs. L. Schmid, W. Pütz and D. Naber of Daimler-Benz (DB), Stuttgart, Germany in supplying the engine and technical support for this testing program.

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## LIST OF ACRONYMS

ADMM15	15% dimethoxymethane in ALS
ALS	Alternative Low Sulfur
CIDI	Compression Ignition, Direct Injection
DOD	Department of Defense
DOE	Department of Energy
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency
NO <sub>x</sub>	Nitrogen Oxides
OEM	Original Equipment Manufacturer
PM	Particulate Matter
SwRI	Southwest Research Institute
TACOM	U. S. Army Tank-Automotive and Armaments Command
TARDEC	U.S. Army Tank- Automotive Research, Development and Engineering Center
TFLRF	TARDEC Fuels and Lubricants Research Facility

## 1. BACKGROUND

The U.S. Department of Energy, with the cooperation of DaimlerChrysler, undertook a series of evaluations of alternative diesel fuel formulation using the newly released Daimler-Benz OM 611 diesel engine as a surrogate for an advanced diesel engine as identified by the Partnership for the Next Generation of Vehicles (PNGV) program. The first phase of this program, completed in 1998 (1)\*, evaluated the exhaust emissions and fuel economy benefits of several alternative diesel fuels without making any adjustments to the engine control system. That work found that large reductions in engine-out particulate emissions were possible with some fuels. In particular, compared to the 49 state on-highway diesel fuel used as a reference, a diesel fuel from the Fischer-Tropsch process, and a fuel consisting of a blend of dimethoxymethane and a Swedish Class 1 City Fuel-like petroleum fraction each reduced particulates on the order of fifty percent without increasing oxides of nitrogen emissions.

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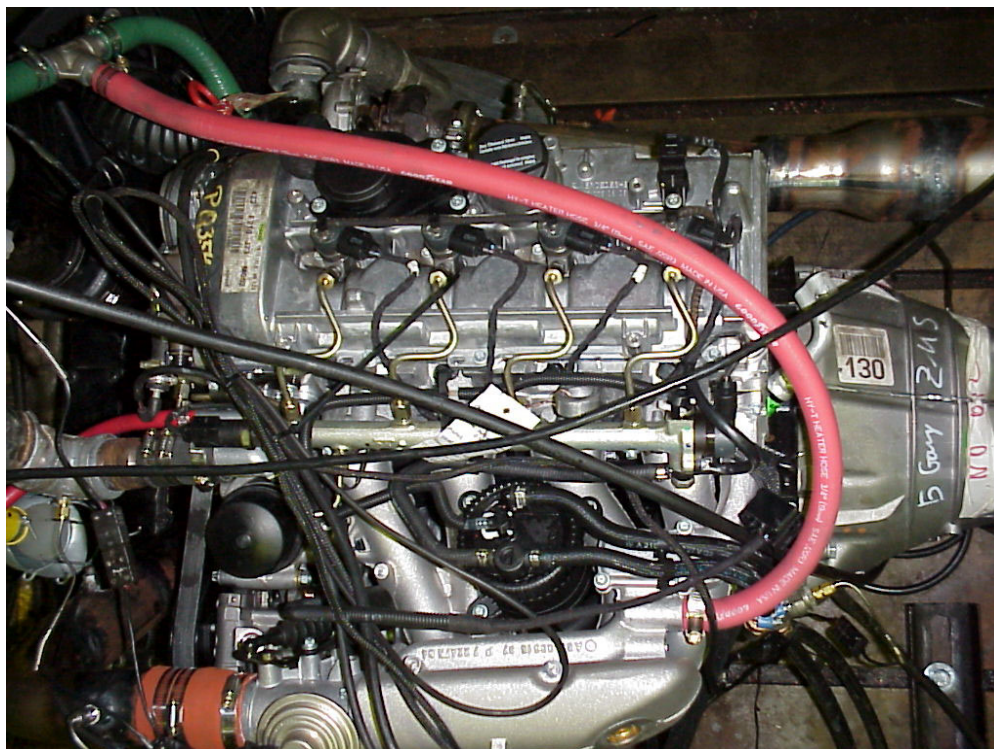
\*Underscored numbers in parentheses indicate references at the end of the document

## 2. EQUIPMENT AND PROCEDURES

A DaimlerChrysler OM611 diesel engine was supplied by Daimler in Germany to support this program, as described in Table 1. This four-valve-per-cylinder engine is turbocharged and intercooled with a high pressure common rail fuel injection system with pilot injection, and includes exhaust gas recirculation, and intake port cutoff. This engine is manufactured for sale in Europe; thus it is calibrated to meet ECE15/EUDC emission standards. The engine would normally run in a light-duty vehicle with two oxidation catalysts in the exhaust system that would reduce the HC and CO emissions from the vehicle (3). No oxidation catalysts were included in the exhaust system for these tests. No engine break-in was conducted, as this engine was operated at DaimlerChrysler before it was shipped to SwRI.

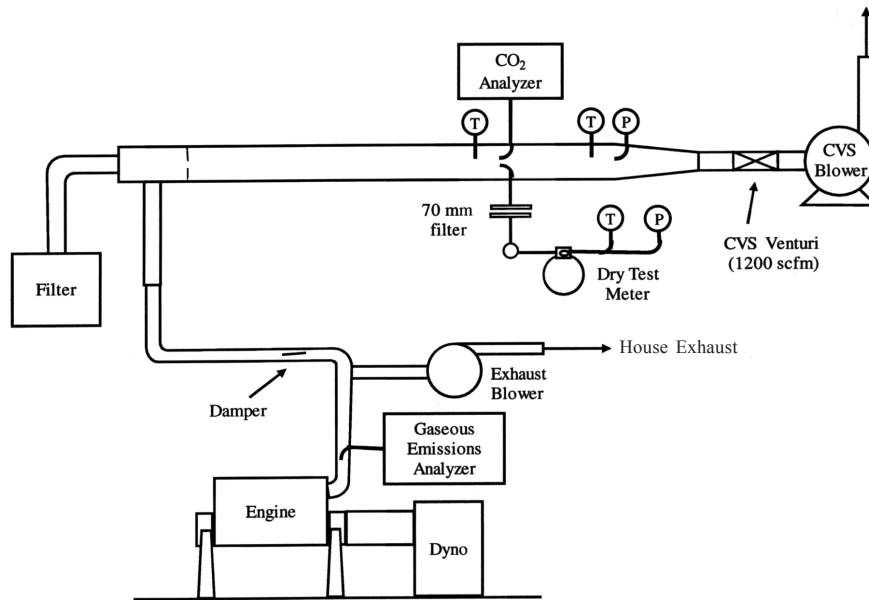
<b>Table 1. Engine Specifications</b>	
<b>Parameter</b>	<b>Specification</b>
Engine Type	Four Stroke/I4/DI
Rated Speed, rpm	4200
Power Output, hp	125
Peak torque Speed, rpm	1800-2600
Peak Torque, lb-ft.	220
Induction	Turbocharged
Intercooling	Air-to-Air
Exh. Restriction, in. Hg.	11.0-at rated engine conditions
Int. Restriction, in. water	16.5-at rated engine conditions
Fuel System	Electronically controlled, high pressure common rail with pilot injection

Two SwRI engineers traveled to Germany to visit DaimlerChrysler, where DaimlerChrysler engineers provided detailed information on the engine systems, and made recommendations for the test-cell configuration at SwRI. The OM611 2.2 liter diesel engine was installed on a test stand as shown in Figure 1, which included facilities for measuring relevant engine operating parameters, and gaseous and particulate emissions. The parameters measured, along with an estimate of accuracy of the measurements, are included as Appendix A. As recommended by DaimlerChrysler, the engine was mounted with the transmission. As a result, the indicated power output includes the fourth gear transmission losses.



**Figure 1. Daimler OM611 Engine Installed on Test Stand**

The OM611 engine was instrumented for the exhaust species list in Table 2 as diagrammed in Figure 2. The gaseous emissions were drawn from the raw exhaust, with a sample probe located approximately three pipe diameters downstream of the turbocharger outlet. The gaseous exhaust sampling probe was located upstream of the back pressure regulating butterfly. The backpressure regulating butterfly was locked in the position that produced 11-in Hg back pressure at rated speed and load. The gaseous emissions sampling was performed in accordance with the guidelines outlined in 40 CFR Part 86, Subpart D. The OM611 engine exhaust was coupled to the house exhaust system and a Constant Volume Sampling (CVS) system. The CVS system consists of a 203-mm dilution tunnel, with a 1200 CFM blower, and a critical flow venturi. In order to attain a 125°F filter face temperature with the CVS system, the engine exhaust was split between the house exhaust and the dilution tunnel. A carbon dioxide tracer technique was utilized to determine the dilution ratio in the CVS system. The particulate matter sampling procedures were performed in accordance with the guidelines established in 40 CFR Part 86, Subpart N.



**Figure 2. Engine Emissions Measurement Configuration**

<b>Table 2. Exhaust Emission Measurements</b>	
<b>Constituent</b>	<b>Analysis Method</b>
Oxygen	Paramagnetic
Total Hydrocarbon	Heated Flame Ionization Detector
Carbon Monoxide	Non-dispersive Infrared Analysis
Carbon Dioxide	Non-dispersive Infrared Analysis
Oxides of Nitrogen	Chemiluminescent Analysis
Particulate Matter	Gravimetric, CVS, CO2 tracer

### 3. Rapid Prototyping Electronic Control System (RPECS)

Preliminary data were collected using the engine in the stock configuration. This data compared favorably with the Phase I results, confirming the operation of the engine. DaimlerChrysler (DC) provided access to the engine control module (ECM) through the controller area network (CAN) interface bus. However, because of intellectual property agreements with Bosch, the manufacturer of the high pressure common rail injection system, DC was unable to provide access to the engine control algorithms. In order to deviate from the factory engine operating settings, the engine's OEM electronic controller was replaced with a SwRI Rapid Prototyping Electronic Control System (RPECS). The RPECS system was developed at SwRI to provide an engine controller which was sophisticated

enough to allow advanced engine (or vehicle) development, with all the control algorithms easily modifiable. This system has also been used, as in this case, to replace the OEM engine control module when access to the factory control algorithms are not possible because of proprietary issues.

The RPECS consists of a personal computer, a multichannel analog-to-digital (A/D) converter card, an SwRI designed engine controller card with separate processor, and external driver cards. The RPECS was installed to monitor all the ECM input and output signals, which allows a preliminary mapping of ECM inputs to control outputs to be made.

The power and rise time requirements of the Bosch fuel injectors on this engine required the design and fabrication of new injector drive electronics in order to obtain appropriate injector performance. During the debugging of the RPECS injector-driver hardware, an injector was damaged. Replacements were obtained through a Mercedes Benz dealer in the United Kingdom because parts for this engine were not available in the United States, and a shortage of spare injectors was occurring in Europe. This significantly delayed the project, and in hindsight brought into question the comparison of these results to those obtained during the earlier project. A comparison of changes in part numbers from this equipment change can be seen in Table 3.

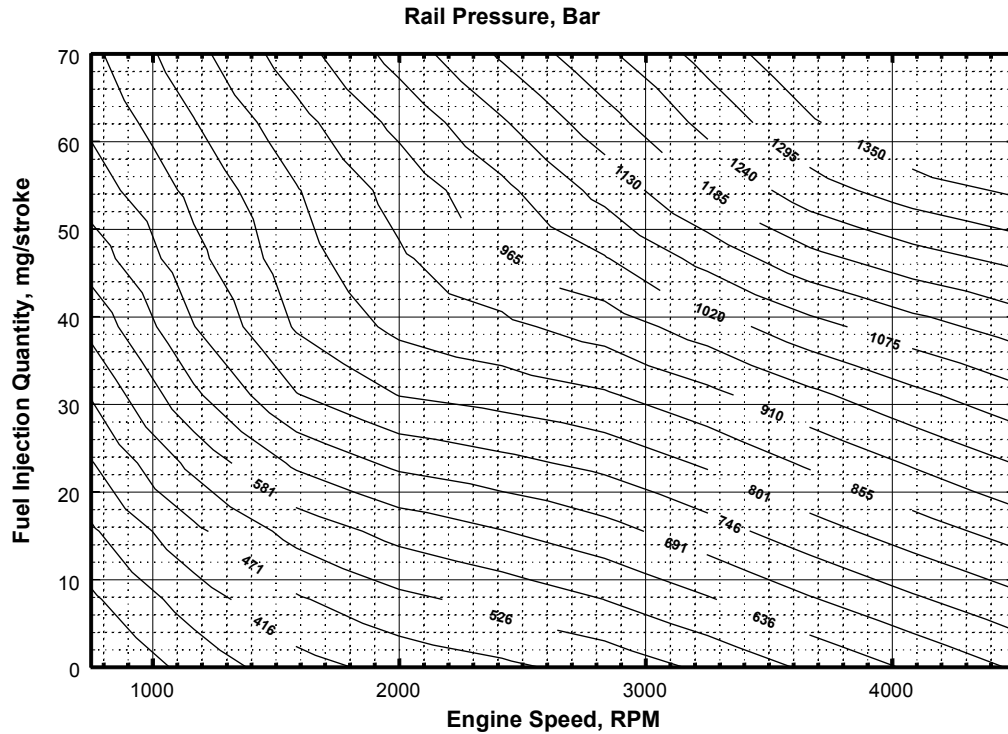
<b>Table 3. Comparison of Changes in Part Numbers</b>			
<b>Source</b>	<b>DC Injector Part No.</b>	<b>DC ECU Part No. DC ECU Serial No.</b>	<b>Comments</b>
Original Equipment	A-611-070-03-87	A-022-545-34-32 SN: R7849	Original Prototype Parts, Injector Coils Damaged
DC Replacement	A-611-070-04-87	A-022-545-34-32 SN: R7310	Prototype ECU Calibrated for New Series Injectors, DC instructions were to replace ECU with injectors
UK Mercedes Dealer	A-611-070-05-87	A-026-545-03-32	Production Components

The Daimler-Benz OM611 engine was operated with both the ECM and the SwRI RPECS at each of the 13 modes outlined in the test plan. While operating on the ECM, the common rail fuel-injection system parameters, main-injection quantity, boost, and EGR controller duty cycle were monitored using the CAN interface. The ECM results were used for comparison to the controller maps when the engine was operating under RPECS control.

The RPECS fuel-delivery requirements are based on the pedal position potentiometer and engine speed. The initial control strategy with RPECS was to control injection pulse width at approximately 1 msec and vary the rail pressure to meet fuel-delivery requirements using a dimensional lookup table. This strategy resulted in high exhaust temperatures for each condition evaluated, indicating the injection duration was excessive. While under RPECS control, the engine injection parameters were fixed at the ECM values for a given test condition. Exhaust temperatures were still excessive, indicating the injection event during RPECS control was retarded. The global TDC offset was advanced six degrees, which resulted in RPECS exhaust temperatures similar to the ECM values.

It was determined that two-dimensional lookup tables for rail pressure and pilot-injection quantity, both as a function of engine speed and fuel delivery, were needed to match ECM engine performance while under RPECS control. A contour plot, Figure 3, was generated from the ECM data to fill out the 2-D table for rail pressure.

The pilot injection quantity under RPECS control was initially set at 3 mg/stroke. The RPECS calculates a pilot quantity pulse width based on the pilot quantity and the rail pressure. Operation of the engine indicated this value was not the best to utilize at all the test modes. At certain conditions, the 3 mg/stroke pilot quantity was excessive and resulted in an increase in engine noise. In most cases, the 3 mg/stroke pilot quantity resulted in a long pilot injection duration. A 2-D table of pilot quantity as a function of engine speed and fuel delivery was added to the RPECS control scheme. The pilot quan-



**Figure 3. Speed, Fuel Delivery, Rail Pressure Relationship**

tity 2-D table was completed by entering a pilot quantity, which resulted in a pilot pulse width that closely matched the ECM control value for each of the 13 test modes.

A comparison of the ECM and RPECS engine control parameters varied in this experiment are shown in Table 4. These data represent the initial attempt to modify the RPECS lookup tables to match ECM performance. Realizing that slightly different control and injector driver strategies are being utilized, the final RPECS map modifications were performed while monitoring emissions and comparing to previous data. The rail pressure and boost are set via closed-loop control. The open-loop EGR duty cycle control was converted to closed-loop by utilizing feedback from the engine mass air flow sensor. The injection timing and duration (both pilot and main) are open-loop control utilizing 2-D lookup tables.

While verifying RPECS control, the fuel-consumption measurement appeared inconsistent. Investigation of the instrumentation indicated a sensor with poor zero stability. The sensor was replaced and calibrated. The fuel-consumption measurement system day tank and regulator exhibited a stick-slip

Table 4. Comparison of ECM and RPECS Engine Control parameters									
speed	load	Controller	Rail Pressure	Pilot Injection Duration	Main Injection Duration	Pilot SOI	Main SOI	boost	EGR Duty Cycle
rpm	lb-ft		bar	msec	msec	DBTDC	DBTDC	bar, g	%
900	2	ECM	306	0.289	0.510	10	0	-0.05	90.0
		RPECS	309	0.371	0.480	10	0	-0.04	90.0
1000	75	ECM	469	0.225	0.758	14	3	0.02	69.4
		RPECS	538	0.248	0.752	14	4	0.05	68.3
1500	33	ECM	461	0.228	0.552	18	1	-0.01	71.5
		RPECS	501	0.255	0.550	17	1	0.04	70.4
1500	112	ECM	718	0.184	0.734	22	6	0.28	5.0
		RPECS	740	0.195	0.742	22	6	0.28	3.8
1500	172	ECM	852	0.161	1.170	22	6	0.59	1.0
		RPECS	853	0.167	1.160	22	6	0.58	1.0
2000	25	ECM	522	0.216	0.491	24	2	0.04	69.5
		RPECS	545	0.243	0.488	24	2	0.03	67.8
2000	189	ECM	953	0.166	1.122	27	5	1.05	1.0
		RPECS	957	0.164	1.130	27	5	1.02	0.0
2300	53	ECM	653	0.196	0.556	29	4	0.26	63.4
		RPECS	686	0.208	0.573	29	4	0.27	60.8
2600	112	ECM	848	0.165	0.658	36	8	0.71	57.7
		RPECS	885	0.159	0.706	36	8	0.72	52.9
2600	219	ECM	1163	0.174	1.240	37	9	1.18	1.0
		RPECS	1172	0.145	1.250	37	9	1.20	0.0
3400	177	ECM	1283	n/p*	1.038	n/p	14	1.02	1.0
		RPECS	1291	n/p	1.049	n/p	14	1.02	0.0
4200	24	ECM	834	0.160	0.417	55	9	0.40	1.0
		RPECS	874	0.164	0.459	55	9	0.46	0.0
4200	146	ECM	1350	n/p	0.912	n/p	19	0.95	1.0
		RPECS	1332	n/p	1.024	n/p	19	0.97	0.0

characteristic. The fuel flow values were not asymptotically approaching a value. Instead, readings revealed that the flow changed in a series of steps. The stability period of the fuel flow measurement was 6 minutes for flow rate increases and 13 minutes for flow rate decrease. Due to the critical nature of the fuel flow measurement with respect to exhaust emission data, this response was deemed unacceptable. A day tank with an order-of-magnitude faster response time was obtained for the test cell.

The engine calibration tables and control signals were duplicated with the RPECS hardware/software, then modified as necessary. A high and a low value of the each of the four engine operating parameters was determined by individually varying each parameter till one of the following occurred; 20% NO<sub>x</sub> increase was noted, a 20% increase in Bosch smoke, rough engine operation, or exhaust temperature exceeded 1450°F.

#### 4.0 TEST FUELS

Three fuels shown to significantly reduce engine-out emissions in the DaimlerChrysler OM611 CIDI engine during the first phase of this program, along with fuels suggested by the Ad-Hoc Fuels Research group, were evaluated for emissions benefits with selected engine control system optimization for each fuel. Because of coordination with other DOE and industrial project activities, these fuels were grouped based on their connection to the previous SwRI project (group A fuels), and those fuels which were new but identical to those being used in complementary external projects (group B fuels). The fuel groupings are summarized in Table 5 and several key physical and chemical properties are shown in Table 6.

<b>Table 5. Test Fuel Groupings</b>		
<b>Fuel Group</b>	<b>Fuel Description</b>	<b>Abbreviation</b>
<b>A</b>	2-D Certification	2D
	Low Sulfur	LS
	California Reference Fuels	CA
<b>B</b>	Fischer-Tropsch	FT100
	Alternative Low Sulfur	ALS
	15% DMM in ALS	ADMM15

Table 6. Properties of Test Fuels

DOE FUELS ANALYSIS 12/23/99			FISCHER- TROPSCH (FT100)	FISCHER- TROPSCH (FT100)	CALIFORNIA REFERENCE (CA)	CALIFORNIA REFERENCE (CA)	ALTER LOW S (ALS) F	ALTER LOW S (ALS) F	DMM/ALS BLEND (ADMM15)	DMM/ALS BLEND (ADMM15)	2D CERT (2D)	LOW SULFUR (LS)
PROPERTY	UNITS	ASTM	SwRI	Core	SwRI	Core	SwRI	Core	SwRI	Core	SwRI	SwRI
Density @ 15C	g/ml	D4052	0.7812		0.8378		0.8160		0.8201		0.8426	0.8119
Distillation		D2887										
IBP	°C		145		145		140		58			
10%	°C		266		192		202		179			
50%	°C		302		251		280		273			
90%	°C		351		325		344		344			
95%	°C		359		339		362		360			
End point	°C		377		372		416		413			
Distillation		D86										
IBP	°C		215	233	189	192	207	210	42	40	183	241
10%	°C		258	256	215	214	232	232	73	61	216	247
50%	°C		289	287	255	253	276	275	264	261	260	252
90%	°C		325	323	309	308	322	321	319	312	309	261
95%	°C		332	330	321	321	334	334	332	325	325	265
End Point	°C		337	336	331	331	344	344	342	338	340	277
Cetane Number		D613	84	87	45	49	63	62	59		44	67
Cetane Index		D976	78		48		61		57		48	57
Kinematic Viscosity at 40°C	cSt	D445	3.2	3.1	2.4	2.3	2.9	2.9	1.9	1.7	2.4	2.4
Flash Point	°C	D93	98	99	72	70	87	87	<2(D56)	<24	71	102
Hydrogen	wt%	D5291	15.1		13.4		14.4		13.7		13.0	14.0
Carbon	wt%	D5291	84.8		86.4		85.6		81.6		86.7	85.8
Oxygen	wt%	difference	0.1		0.2		0.0		4.7		0.3	0.2
Nitrogen	µg/g	D4629	7.8		<1.0		<1		<1		60	<1
Sulfur	ppm	D2622	<10		176		<10		<10		337	2

Table 6. Properties of Test Fuels (continued)												
DOE FUELS ANALYSIS 12/23/99		FISCHER- TROPSCH (FT100)	FISCHER- TROPSCH (FT100)	CALIFORNIA REFERENCE (CA)	CALIFORNIA REFERENCE (CA)	ALTER LOW S (ALS)	ALTER LOW S (ALS)	DMM/ALS BLEND (ADMM15)	2D CERT (2D)	LOW SULFUR (LS)		
		AL25323F	AL25323F	AL25713F	AL25713F	AL25383F	AL25383F	AL25469F	AL25714	AL25717		
Hydrocarbon Type:												
Total Aromatics	wt%	D5186	0.2	<0.1	18.9	18.6	9.0	9.1	8.2*	9	30.3	0.2
Mono	wt%	D5186	0.2		15.1		8.5		7.8*		21.4	0.2
Poly(Di+ Tri)	wt%	D5186	<0.1		3.8		0.5		0.4*		8.9	<0.1
Paraffins	wt%	D2425	97.1		44.2		54.5		54.2*		42.8	64.0
Napthenes	wt%	D2425	2.9		37.8		36.9		31.9*		28.8	33.8
Water	ppm	D4928	45.0		105.0		77.0		368.0		98.0	75.0
Color		D1500	LO.5		LO.5		LO.5		LO.5		1.0	LO.5
Clear and Bright		D4176	PASS		PASS		PASS		PASS		PASS	PASS
Particulates	mg/L	D6217	4.3		<0.01		0.8		0.7**		0.3	<0.01
Copper Strip Corrosion		D130	1a		1a		1a(50C)		1a		1a	1a
Cloud Point	°C	D2500	-1		-27		-4		-7		-18	-10
Pour Point	°C	D976	-2		-32		-5		-9		-24	-7
Carbon Residue	%	D524	0.071		0.220		0.080		0.038		0.240	0.570
Acid Number	mgKOH/ g	D664	0.03		0.02		0.02		0.02		0.02	0.03
Oxidation Stability		D2274	0.20		0.20		<0.01		0.25***		<0.01	<0.01
Net Heat of Combustion	MJ/kg	D240	43.9		42.7		43.3		40.8		42.5	43.3
Gross Heat of Combustion	MJ/kg	D241		47.2		46.0		46.8		42.0		
Lubricity	mm	HFRR	0.59		0.27		0.57		0.49		0.57	0.59
BOCLE Scuff	grams	D6078	1900		4300		1600		1950		2850	1550
Sulfur by X-ray Spect	wt%	D4294				0.021						
*The DMM is interfering with these results **DMM altered shape of filter and may be interfering with results ***Vigorous boiling occurred as sample came to temperature.												

The volatility of the DMM blend caused problems with several of the property tests designed for diesel fuels. The flash point for the DMM blend was too low for D 93, the diesel fuel procedure, and it was necessary to use the gasoline procedure, D 56. During the oxidation stability test, D 2274, the sample was boiling, which will produce a questionable result. The tests for aromatics for the blend differs from the values predicted by simply multiplying the ALS aromatics result by 0.85%. The cause(s) of the differences has not been determined.

## V. EXPERIMENTAL DESIGN

When optimizing the engine control systems for each of the test fuels, an immediate concern was to define the optimization goal or optimization function. Since this work was to be conducted with the focus on engine-out emissions without consideration for a specific aftertreatment device or vehicle configuration, there was no obvious way to apply the EPA certification standards. A number of options were apparent:

- Minimum NO<sub>x</sub> – Minimize NO<sub>x</sub> emissions without a change in the engine thermal efficiency. Options here included:
  - Minimize NO<sub>x</sub> emissions without PM increase and with a constraint on amount of fuel consumption increase.
  - Minimize NO<sub>x</sub> emissions at best achievable specific fuel consumption, with a constraint on the PM emissions.
- Minimum PM – Minimize PM emissions without an increase in NO<sub>x</sub>.
- Minimum BSFC – Maximize engine efficiency with minimum NO<sub>x</sub> emissions, with a constraint on PM.
- Minimize sum of NO<sub>x</sub> and PM – Minimize a “regulation-like” weighting, constrained by a maximum allowable BSFC increase.

This certainly isn't an exhaustive list, but illustrates the types of optimization options possible. After several discussions with the sponsor, the decision was made to develop a statistical design strategy which would produce a response surface model. This response surface model could be used for numerical evaluation of a variety of optimization functions, without further engine testing.

Several engine parameters may have an influential effect on the engine emissions and fuel economy. Four engine parameters (factors) were chosen for study and optimization. These were exhaust gas recirculation (EGR), boost pressure, fuel injection timing, and pressure in the common rail injection system which affects injection rate. All of these factors are defined as continuous factors; i.e., they may assume any numeric values within a range.

Levels at which each of these engine factors were tested were established by varying  $x\%$  off the stock engine control operating targets. Each engine factor could be tested at high, middle and low values of the defined operating range. These levels also changed depending on the mode (load/speed condition) being simulated. The resulting test conditions developed by this approach are listed in Table 6a.

A statistical experimental design strategy was used in this study for several reasons:

- statistically designed experiments are economical,
- the influence of one or more factors on a response can be measured,
- estimation of the experimental error is feasible,
- synergistic effects can be modeled, and
- it allows estimation of a response surface model.

The design strategy chosen involves an algorithmic methodology in which the design is calculated by searching a list of candidate test runs. This set of candidate test runs covers the areas defined by the ranges of the engine factors. The candidate set is also guided by the format of the response surface model chosen for investigation.

Table 6a. Response Surface Experiments Group A and Group B Fuels Ranges for Independent Factors of Steady-State Test Points												
Factors	Mode	M5	M6	M8	M10	M11	M12	M16	M17	M18	M19	M20
	Speed	2600	2300	2000	2000	1500	900	3400	2600	1500	1500	1000
	Load	111	53	189	25	33	1	177	220	183	111	75
EGR Controller Mass Air Flow	Low	64	50	62	34	25	16	75.7	73.6	0*	42	25
	Middle	66	57	64	40	30	24	78.2	74	35*	44	27.8
	High	68.5	64	66	45	35	32	80.7	74.35	65*	47	30.5
Boost Level, Bar gauge	Low	0.5	0.1	0.75	N/A‡	N/A	N/A	0.9	1.14	0.55	0.17	0
	Middle	0.7	0.22	0.9	N/A	N/A	N/A	1	1.22	0.58	0.23	0.01
	High	0.91	0.33	1.05	N/A	N/A	N/A	1.1	1.3	0.61	0.28	0.02
Rail Pressure, Bar	Low	750	500	850	400	350	250	1200	1090	600	550	400
	Middle	875	625	925	550	550	325	1275	1135	800	738	550
	High	1000	750	1000	700	750	400	1350	1180	1000	925	700
Start of Main Injection Timing, DBTDC	Low	5	1	3	-2	-4	-2	12	8	0	2	-2
	Middle	7	4	5	3	2	4	14	9	5	5	3
	High	9	7	7	8	8	10	16	11	10	8	8
* EGR open loop duty cycle controller values instead of closed loop mass air flow values.												
‡ Not applicable due to inability to control boost at light load, or no dependent variable response to independent variable change												

Since the four engine factors are continuous in nature, a polynomial model can be used to approximate a hypothetical surface of the response (engine emission or fuel economy). It was also assumed that the relationship between the engine factors and the response could be nonlinear. Therefore, a second-order (full quadratic) polynomial model was chosen to base the search of candidate test runs. This model included linear, interaction, and quadratic terms of the engine factors.

A 13-mode test sequence defining the speed/load operating conditions, is listed in Table 7 and illustrated in Figure 4.

Preliminary trials of the initial four-factor design found that turbocharger boost pressures other than the maximum available invariably increased particulate emissions dramatically, and would result in exces-

Table 7. Steady-State Test Points						
Engine Mode	Test Matrix			Definition		
	Phase I	Phase II (Group A & B Fuels)	Auto/ Energy Modes	Engine Speed (RPM)	BMEP (bar)	OM611 Equivalent Torque (ft-lb)
M1	✓			4200	9.3	117
M2	✓			4200	6.2	78
M3	✓			3400	8.8	111
M4	✓			2600	13.1	166
M5	✓	✓	✓	2600	8.8	111
M6	✓	✓	✓	2300	4.2	53
M7	✓			2000	17.5	100 %
M8	✓	✓		2000	15.0	189
M9	✓			2000	8.8	111
M10	✓	✓	✓	2000	2.0	25
M11	✓	✓	✓	1500	2.62	33
M12	✓	✓	✓	900	0.1	1-2
M13	✓			765	0.1	1-2
M14		✓		4200	12.0	152
M15		✓		4200	2.0	25
M16		✓		3400	14.0	177
M17		✓		2600	18.0	229
M18		✓		1500	14.5	183
M19		✓		1500	8.8	111
M20		✓		1000	6.0	75

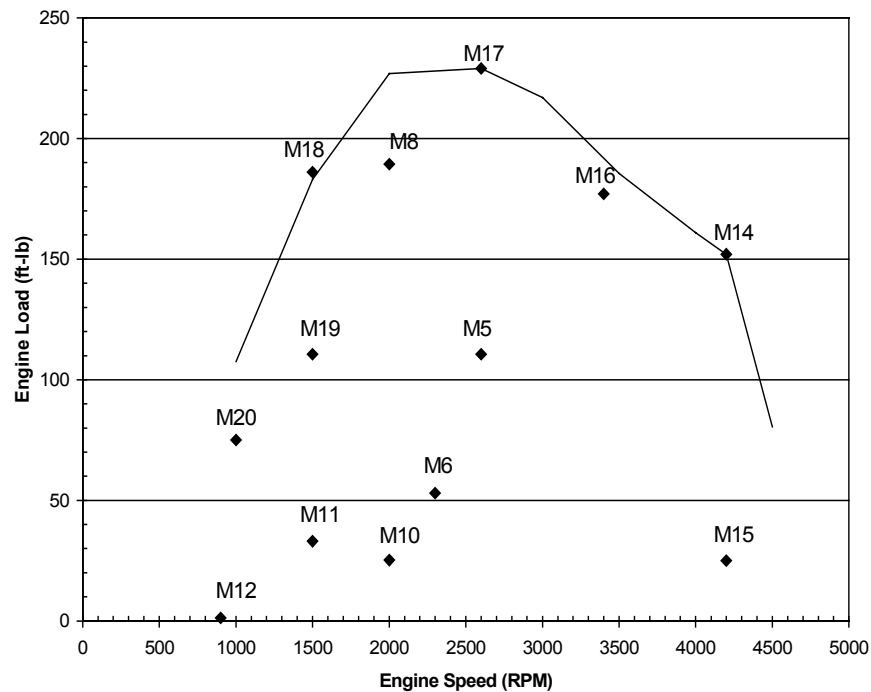


Figure 4. Engine Test Point location Within Torque Envelope

sive exhaust gas temperatures. As a result, after some initial evaluations, this variable was eliminated, and a three-factor design was used. Thus, a quadratic model using the remaining three engine factors consists of the following terms:

$$\begin{aligned} \text{Response} = & \text{constant} + C_1 \text{EGR} + C_2 \text{Rail Pressure} + C_3 \text{Injection Timing} + C_4 \text{EGR} * \text{Rail Pressure} + \\ & C_5 \text{EGR} * \text{Injection Timing} + C_6 \text{Rail Pressure} * \text{Injection Timing} + C_7 \text{EGR}^2 + C_8 \text{Rail Pressure}^2 + \\ & C_9 \text{Injection Timing}^2 \end{aligned}$$

where  $C_1$ - $C_9$  are coefficient estimates based on least-squares regression techniques

Once the models were selected, a search was conducted for a set of candidate test runs. The minimum number of test runs possible is the number of terms in the model. Designs for this minimum number can always be constructed, but it is not recommended because it would not be possible to test the coefficient estimates for statistical significance. In order to do this, repeat test runs need to be added to the total test matrix. This will ensure the ability to estimate the residual standard deviation, which can then be used to test the statistical significance of the estimates. Five repeat tests were selected for both of the test matrices. Also, an indication of the design's "goodness" was characterized by computing the design's G-efficiency. Designs which have g-efficiency values greater than 50% are all good designs. The g-efficiency of the 3-factor design was 78.8%. The resulting design test matrices for the 3-factor model is given in Table 7. Note that test runs with the same number are repeat runs. Also, test run values for the engine factors are denoted as 0, .5, and 1 for the low, middle, and high factor levels.

A partial factorial design of experiment approach was to develop a quadratic response surface model for PM, NO<sub>x</sub> and fuel consumption at each speed/load point as a function of the 3 engine operating parameters. The resulting surface would then be used to find optimum engine control conditions to achieve desired emission goals.

For the design, Table 8, a “0” represents the low, “0.5” the middle, and “1” the high factor levels from Table 1. The three factor design for each mode and fuel contains 20 experiments.

<b>Table 8. Three Factor Experimental Design</b>			
<b>Run Number</b>	<b>EGR</b>	<b>Rail Pressure</b>	<b>Injection Timing</b>
1	0	1	1
2	1	1	0
3	1	0.5	0
4	0.5	0.5	1
5	1	0	0.5
6	0	1	1
7	0.5	0.5	0.5
8	1	1	1
9	0	0	0
10	1	0	1
11	0	0	0
12	0.5	0	0
13	0	0.5	0.5
14	1	0	0
15	1	1	0
16	0.5	0.5	0.5
17	0.5	1	0.5
18	0	0	1
19	1	0	1
20	0	1	0

The run order for the test runs compiled for each test matrix were completely randomized, including repeat tests. Once the test matrix was randomized, the same test run sequence was used for each mode. For each fuel, the 13 modes were run in the following, fixed run order: mode 12, mode 20, mode 11, mode 19, mode 18, mode 10, mode 6, mode 5, mode 8, mode 17, mode 16, mode 14, and mode 15.

## 6.0 LOCATION OF PEAK PRESSURE (LPP) FUEL COMPARISON

As described in the later portions of the discussion of results section, near the end of the project another technique, referred to as the Location of Peak Pressure (LPP) method, was used for comparison of the performance of some of the test fuels. The OM611 diesel engine was run at five different engine speeds and loads and controlled to hold the location of peak pressure of combustion at 7°ATDC. Individual cylinder balance was maintained within 5% of the Indicated Mean Effective Pressure (IMEP), with pilot fuel injection disabled. Particulate filter samples were collected at each load and control condition. The particulate matter was sampled from a 203mm-dilution tunnel using carbon dioxide tracer for determining dilution ratio. The engine operating conditions are shown in Table 9.

The five test fuels evaluated using this method are shown in Table 10.

Table 9. OM611 Engine Operating Conditions for LPP Evaluations			
Mode	RPM	BMEP, bar	%EGR
M 12	900	0.10	40
M 11	1500	2.62	30
M 10	2000	2.00	30
M 6	2300	4.2	15
M 5	2600	8.8	5

Table 10. Test Fuels for LPP Evaluations	
Fuel Code	Description
CA	California Reference Diesel Fuel
ALS	Low Sulfur Diesel Fuel
FT-100	Fischer-Tropsch Diesel
ADMM15	Oxygenate Blend: 15% Dimethoxymethane in ALS
2DL	EPA 2D Certification Fuel

## 7.0 DISCUSSION OF RESULTS

During the course of operation, it became apparent that the peak load modes (modes 8, 16, and 17) would require a reduction in the load set point value. The sensitivity study varied the factors independently; the experiment varied all four factors in various combinations. At the peak loads the exhaust temperature limit was exceeded by some of the factor combinations. For example, an experiment that contained retarded injection timing along with a low rail pressure resulted in an excessively long fuel-injection event in order to meet the load set point. The RPECS was performing closed-loop control on engine torque by varying the fuel injection quantity. Because all the other common rail injection system parameters are fixed by the experiment, the only variable left to control for fuel quantity was main injection pulse width. The peak load set points were lowered by 5 ft-lbs to provide enough reduction in the exhaust temperature to ensure engine durability.

In order to assess the repeatability of the test engine and instrumentation, the matrix of engine conditions shown in Table 11 was run. In this matrix, four engine modes were repeated in random order. The base 2D certification fuel was used. The RPECS parameters were run at the base values. The resulting estimate of the 95% repeatability limits for emissions and specific fuel consumption are given in Table 12. An interpretation of the repeatability limit is, “The difference between successive results obtained by the same operator with the same apparatus under constant operating conditions on identical test material (fuel) would in the normal and correct operation of the test method exceed the listed limit only one case in twenty.”

<b>Table 11. Repeatability Evaluation Conditions</b>		
<b>Test Mode</b>	<b>Number runs</b>	<b>Notes</b>
6	4	
5	3	only 2 for PM
8	3	
11	4	only 2 for PM

<b>Table 12. 95 Percent Repeatability Limits</b>	
<b>Measured Variable</b>	<b>Repeatability Limit</b>
NO <sub>x</sub> (g/hp-hr)	0.985
NO <sub>x</sub> Index (%)	0.625
CO (g/hp-hr)	2.920
HC (g/hp-hr)	0.392
PM (g/hp-hr)	0.237
BSFC (lb/hp-hr)	0.057

Engine testing to determine the response surface coefficients for all the fuels was completed, and the coefficients were calculated for all modes of the Group B fuels and all modes of the 2D Group A fuel. Several validation experiments were performed based on the optimization models generated from the engine response surfaces. The validation experiments were for Mode 6, utilizing the CARB, ALS, FT100, and ADMM15 fuels. The initial optimization models for the four fuels included minimum NO<sub>x</sub> at the BSFC predicted by the engine parameter midpoint values and the minimum combination of NO<sub>x</sub> and PM.

Following this repeatability determination, testing according to the experimental design was begun. Several issues arose that would have a major impact on the final project results. The variability of the emission measurements were in many cases greater than predicted by the earlier repeatability study. Initially, the poorer than anticipated repeatability was believed to be an operator training problem, where the operators were not setting the engine operating conditions with sufficient precision. Investigation found that there was considerable difficulty setting the EGR rate to the target value, with minor variations in several of the engine conditions making a large change in the EGR rate obtained at a specific EGR control valve setting. Despite several revisions to the engine test setup, this problem hampered the data collection throughout the project.

Investigation also found errors in some of the fuel flow measurements. Several problems were found. The known problem of vapor formation with the DMM15 fuel required revisions in the fuel system

plumbing. During this redesign, a problem was found in the fuel temperature control system. The original system would allow variation in the fuel temperature, which would change the volume of fuel in the system downstream of the fuel day tank. This volume change would cause an interruption in the fuel flow into the day tank, and variations in the apparent fuel consumption as measured upstream of this fuel control system. The data acquisition system would take periodic readings of the apparent fuel flow, then average these readings over the emission sampling period to calculate the fuel flow over the period of the emission measurement. Depending on the thermal cycling of the fuel temperature controller, an unknown but varying error would be introduced into the fuel flow measurements.

Efforts were made to validate the fuel flow. Air/Fuel ratios were calculated from the emissions measurements and compared to the measured air/fuel ratios to determine data points that do not follow the expected trends. Modifications were also made to the fuel flow rate instrumentation to improve the repeatability and quality of the BSFC determinations.

Response surfaces were fit for emissions and BSFC responses for all 11 modes for all test fuels. Table 13 indicates the range of  $R^2$  values for these response surfaces. An example set of response surface coefficients for the 2D fuel, along with measures of goodness of fit, can be found in Appendix B.

<b>Table 13. Range of <math>R^2</math> for Group B Fuels</b>		
<b>Mode</b>	<b>NOx</b>	<b>PM</b>
	<b><math>R^2</math></b>	<b><math>R^2</math></b>
12	.90-.99	.73-.88
20	.79-.89	.84-.99
11	.81-.99	.64-.92
19	.80-.91	.70-.89
18	.61-.95	.77-.96
10	.92-.99	.58-.85
6	.96-.99	.89-.98
5	.82-.99	.92-.97
8	.89-.99	.67-.94
17	.81-.93	.73-.95
16	.97-.98	.81-.90

There were several areas of concern. Some test modes had better model fits than others. Mode 12 was particularly variable due to the difficulty in controlling the engine at this extremely low (virtually idle) condition. At this condition, where engine power is just sufficient to overcome engine friction, minor variations in engine or ambient conditions may have a substantial impact on engine-out emissions.

A second issue was that the experimental design was developed by selecting operating modes based on the factory operating calibrations, then moving the various control variables away from these initial conditions. The impact of variation of each variable was determined independently during the experimental design phase. During the experimental phase when the engine control variables were jointly changed from the original calibration, the emissions impacts were much larger than the sum of the individual variations. While this had been anticipated, this effect not only increased the range of emissions variation, but also seemed to substantially increase the variability of the measurements.

The large variability of the measurements raised doubts about the usefulness of this approach. In order to evaluate the usefulness of the resulting regression surfaces, a set of optimization experiments were performed mathematically, using the response surface models for modes 5, 6, 10, and 11 for all 8 fuels. These modes were selected because they seemed to have the best combination of goodness of fit measures. The optimization strategies were chosen to attempt to bound the region of most interest in the regression surfaces. The three objective points were determined by:

1. Locating the minimum BSFC for each fuel from the response surface models for modes 5, 6, 10, and 11. Identify the engine parameter settings and predict the  $\text{NO}_x$  and PM at those same settings.
2. Locating the minimum  $\text{NO}_x$  for each fuel from the response surface models for modes 5, 6, 10, and 11 of the base level of BSFC. Identify the engine parameter settings and predicted the BSFC and PM at those same settings.

3. Constraining the response surface models at minimum BSFC + 10% and then locating the minimum  $\text{NO}_x$  for modes 5, 6, 10, and 11. Identify the engine parameter settings and predicted PM at those same settings.

It was felt that these three optimization constraints would form a boundary of likely engine operating conditions. That is, step 1 would yield the operating point for best fuel consumption, irrespective of the resulting emissions. Step 2 would reduce  $\text{NO}_x$  without a fuel economy loss, but probably with an increase in particulate. Step 3 would further reduce  $\text{NO}_x$ , but with some sacrifice in fuel consumption. For comparison purposes, the results were averaged over the four testing modes to generate a “composite” response. Figure 5 is a plot of predicted  $\text{NO}_x$  vs. predicted BSFC. Figure 6 is a plot of predicted  $\text{NO}_x$  vs. predicted PM by fuel.

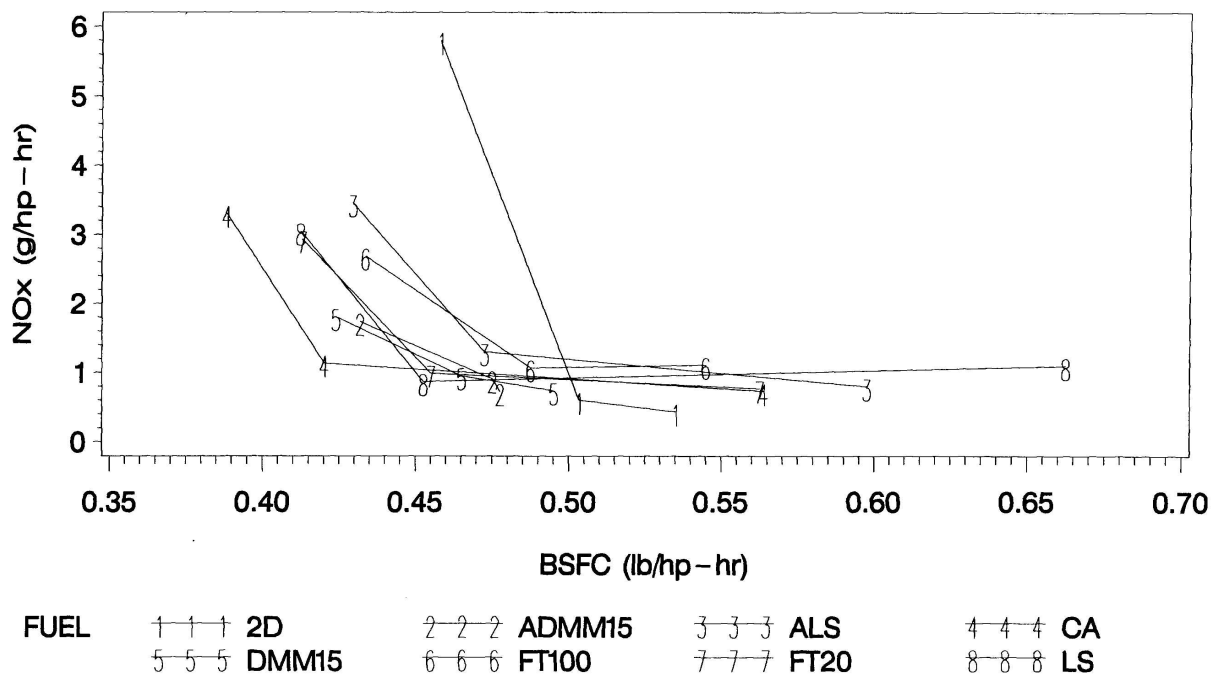


Figure 5. Predicted  $\text{NO}_x$  - BSFC Trade-off for Fuels

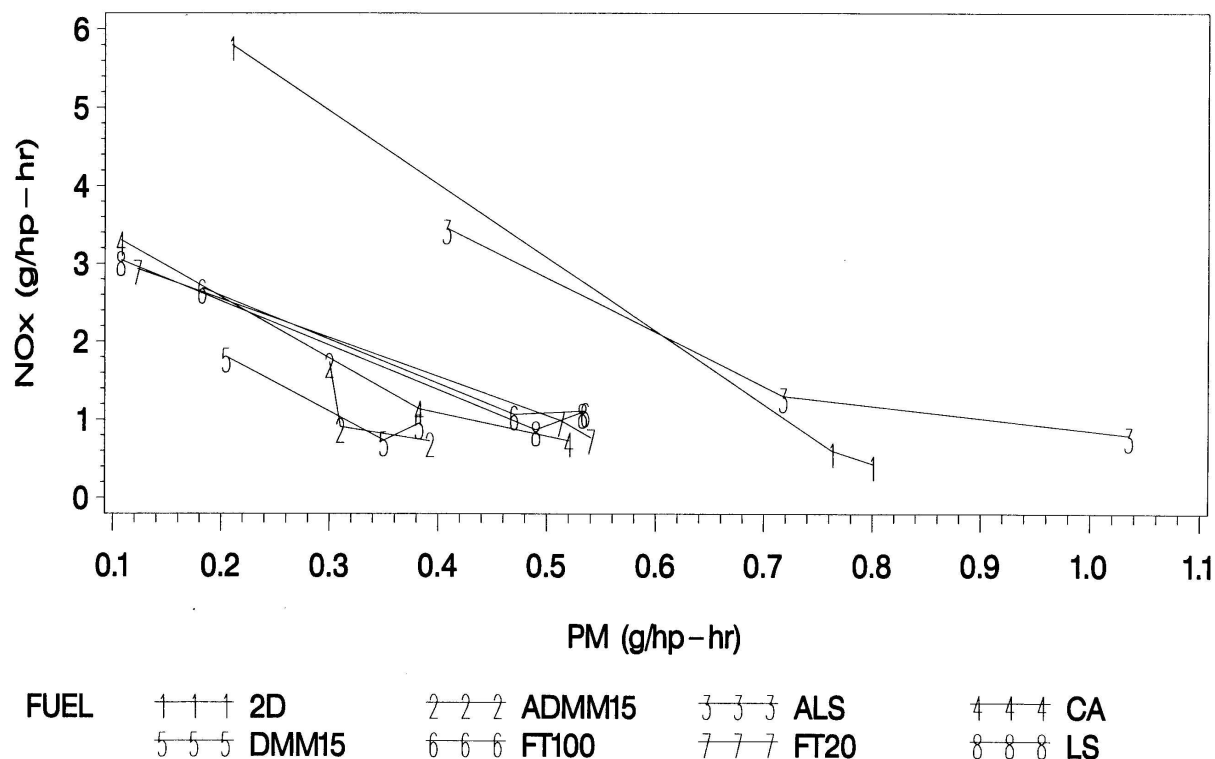


Figure 6. Predicted Composite NO<sub>x</sub> - PM Trade-off for Fuels

The results seemed encouraging, at least when examining the NO<sub>x</sub> vs. particulate curves. The 2D and ALS fuels were very similar, with the ADMM15 and DMM15 also similar to each other. The remaining fuels formed a third group lying between these two extremes. However, the FT100 fuel was predicted to have emissions similar to that of CA and LS. Thus the lower emissions previously measured with FT100 were not reflected in the response surface models.

The NO<sub>x</sub> vs. BSFC curves were more discouraging. There were large differences between the minimum BSFC of the various fuels, which had no apparent relationship to the fuel properties. Considering the earlier problems which had been discovered with some of the fuel consumption measurements, these results further reduced confidence in the fuel measurements.

## 8.0 Validation of Models

As the next step in evaluation of the regression models, engine validations of the optima determined for the low sulfur fuel (ALS) were performed for three engine test modes. The optimization criteria was to find the best combination of the four engine parameters, injection timing, %EGR, injection rail pressure, and boost, which resulted in the lowest particulate matter (PM) when the  $\text{NO}_x$  was constrained to the 2D fuel baseline  $\text{NO}_x$  level. The 2D fuel baseline was determined using the RPECS system set to the stock ECU values. The results were summarized in Table 12. Duplicate runs for Modes 10, 11, and 16 were run and are indicated by the “A” following the mode number. Mode 10 is 2000 rpm and 25 lb.-ft torque, Mode 11 is 1500 rpm and 33 lb.-ft, and Mode 16 is 3400 rpm and 177 lb.-ft. The baseline  $\text{NO}_x$  2D stock values for each mode are listed in Table 14.

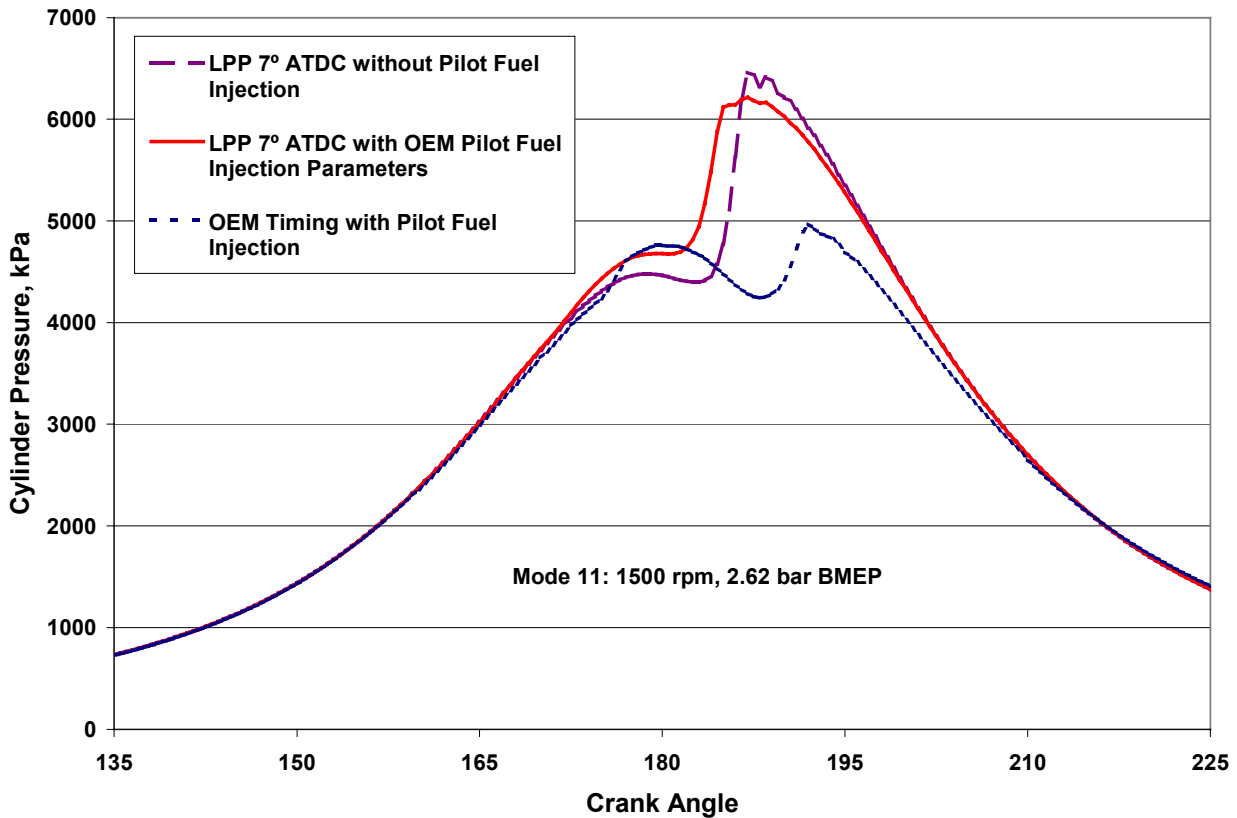
Following the stock values, the  $\text{NO}_x$  levels predicted by the model are listed. The predicted stock values are very close to the 2D stock values because this was the limiting constraint of the optimization. In the third column, the  $\text{NO}_x$  measured while the engine was operated at the predicted optimum conditions is presented. Variation of the measured from the predicted values represents the error in the optimization method and the ability of the engine to repeat  $\text{NO}_x$  emission levels. The PM levels for the 2D stock fuel are given in the next column, followed by the predicted PM levels for the low sulfur fuel at optimum conditions. For Mode 10, a three-fold reduction in PM was predicted, at Mode 11, less than half the baseline PM was predicted, and for Mode 16, one tenth the PM was predicted. The next column to the right shows what PM level was actually measured. Comparing predicted PM to the measured indicates that some improvements in PM were seen but were not as great as those predicted. The differences between the predicted and measured values are the result of errors in the method and repeatability of the engine. The last two columns present the measured and 2D stock values of the BSFC (brake specific fuel consumption). In all the modes, fuel consumption was improved by using the low sulfur fuel at the optimized conditions as compared to the baseline.

Table 14. Engine Validations of LS fuel:									
Mode	NOx 2D Stock RPECS g/bhphr	NOx Exh predicted g/bhphr	NOx Exh measured g/bhphr	PM 2D Stock RPECS g/bhphr	PM Exh predicted g/bhphr	PM exh measured g/bhphr	bsfc measured lb/bhphr	bsfc 2D stock lb/bhphr	
10	1.19	1.19	0.75	0.36	0.11	0.34	0.598	0.616	
10A*	1.19	1.19	0.60	0.36	0.11	0.25	0.569	0.616	
11	0.90	0.90	0.45	0.32	0.13	0.20	0.472	0.5	
11A	0.90	0.90	0.42	0.32	0.13	0.20	0.474	0.5	
16	4.78	4.77	5.07	.020	0.02	0.13	0.383	0.396	
16A	4.78	4.77	4.44	0.20	0.02	0.35	0.386	0.396	
Stock engine parameters programmed in the RPECS:									
Mode	Timing 2D stock/Optimum DBTDC	EGR 2D stock/Optimum %	Rail 2D stock/Optimum bar	Boost 2D stock/Optimum bar					
10	2/3.16	28.9/36.12	522/697	0/0					
11	1/2.14	31.6/37.1	461/662	0/0					
16	14/14.44	0/0.78	1283/1308	1.02/0.91					
Note: run 10 A is a repeat of run 10									

Although the engine validation predicted the proper trends in the engine response, and improvements in the emission levels of PM were obtained at lower fuel consumption, it was felt that the overall method was not sufficiently accurate. The resulting response surface model, when completed, did not adequately model the engine-out emissions. Analysis of the statistical results suggest that the operating extremes generated by combining already broadly varied control settings resulted in engine responses that varied more “steeply” than the selected model would accurately represent. However, examination of the collected data clearly showed that reductions in both  $\text{NO}_x$  and PM from the OEM conditions were achievable.

Therefore, with the concurrence of the DOE, it was decided to discontinue further work on this optimization method and adopt the method used by SwRI for the DOE toxicology project. In that project, the optima were determined by varying the injection timing to locate the peak cylinder pressure (LPP method) at 7 degrees after top dead center. The other engine parameters were set to the levels supplied by the Ad-Hoc Fuels Research group, who provided oversight to that project. This project will use this LPP method to determine the optima for each of the test fuels.

Figure 7 shows cylinder pressure traces for three fuel injection control strategies for the Mode 11 operating condition. The long-dashed line represents the cylinder pressure generated due to a single fuel injection event, timed to maintain the Location of Peak Pressure (LPP) at 7° ATDC. The solid line represents fuel injection timing controlled to maintain the LPP at 7° ATDC, but includes the OEM pilot fuel injection quantity and timing advance. With respect to the single injection event, the pilot fuel injection reveals an increase in cylinder pressure before TDC, with slightly lower peak pressure and pressure rise rate. The short-dashed line represents the OEM injection timing, which includes pilot fuel injection, for the Mode 11 operating condition. The LPP for the OEM timings is 12° ATDC, and an increase in cylinder pressure is seen at TDC due to the combustion of the pilot fuel quantity. The rate of pressure rise and the peak pressure with the OEM strategy are substantially lower than the LPP 7° ATDC approach, resulting in a much quieter engine.



**Figure 7. Cylinder Pressure Traces at Various Timing and Pilot Fuel Injection Conditions**

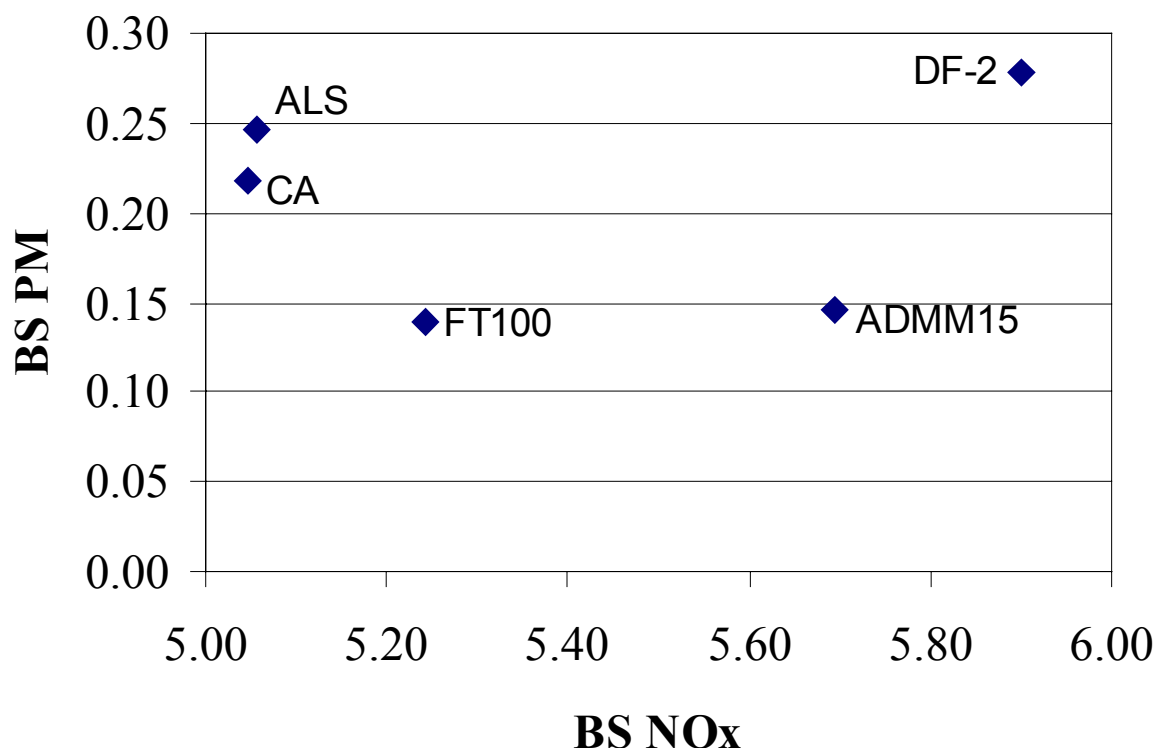
By locating the peak cylinder pressure at 7 degrees after top dead center of the compression stroke, the timing is effectively altered to achieve best specific fuel consumption. The initial EGR rate was selected to minimize  $\text{NO}_x$  while not operating too close to the point at which PM begins to increase rapidly. Boost is set to the maximum achievable at the condition, and the intake manifold swirl valve and the rail pressure is set according to the original OEM ECU settings.

The LPP method requires that the engine be instrumented with pressure transducers in each cylinder, so that the peak pressure location as well as the BMEP can be equal among all for cylinders. The engine that had been used for this project is not instrumented for cylinder pressure, so to minimize cost and time, it was decided to conduct the LPP method based testing in the engine that was used for the DOE toxicology project.

The results of the fuels comparison with the LPP method, where the injection timing is revised for each fuel in order to obtain maximum thermal efficiency, is summarized in Table 15. As illustrated in the column Significant Fuel Groups, there were statistically significant differences among the five fuels, averaged over the operating modes. Also, except for BSCO<sub>2</sub>, there were fuel by mode interactions, indicating that the specific operating mode must be considered in the fuel comparisons.

Table 15. Fuel Comparison Results with LPP Method				
Response	Five Fuels, Modes 5, 6, 10 and 11			
	Fuel	LS Means <sup>1</sup>	Significant Fuel Groups <sup>2</sup>	Significant Interaction
BSHC	DF-2	1.0307	A	Fuel*Mode
	CA	0.8661	B	
	ALS	0.5625	C	
	ADMM15	0.5191	C	
	FT-100	0.3026	D	
BSCO	DF-2	3.6162	A	Fuel*Mode
	CA	3.4670	A	
	ALS	2.2725	B	
	ADMM15	2.2178	B	
	FT-100	1.3808	C	
BSNOX	DF-2	5.9005	A	Fuel*Mode
	CA	5.6960	A	
	ALS	5.2412	B	
	ADMM15	5.0568	B	
	FT-100	5.0467	B	
BSCO2	DF-2	884.0690	A	NS
	CA	874.4240	A	
	ALS	844.6650	B	
	ADMM15	843.9800	B	
	FT-100	812.4020	C	
PM	DF-2	0.2774	A	Fuel*Mode
	CA	0.2471	AB	
	ALS	0.2177	B	
	ADMM15	0.1454	C	
	FT-100	0.1397	C	
BSSOF	DF-2	0.2091	A	Fuel*Mode
	CA	0.1906	A	
	ALS	0.1510	B	
	ADMM15	0.1251	B	
	FT-100	0.0812	C	
1Factor levels listed from highest to lowest least squares mean				
2 Letters designate groups of factor means within which there are no statistical				
NS=no statistically significant differences i the mean response at the 5%				

As illustrated in Figure 8, there is a statistically significant reduction in BS PM with both the ADMM15 and FT100 fuels, compared to the others. These two fuels reduce PM to approximately 50 percent of the PM emissions with the DF-2 fuel.



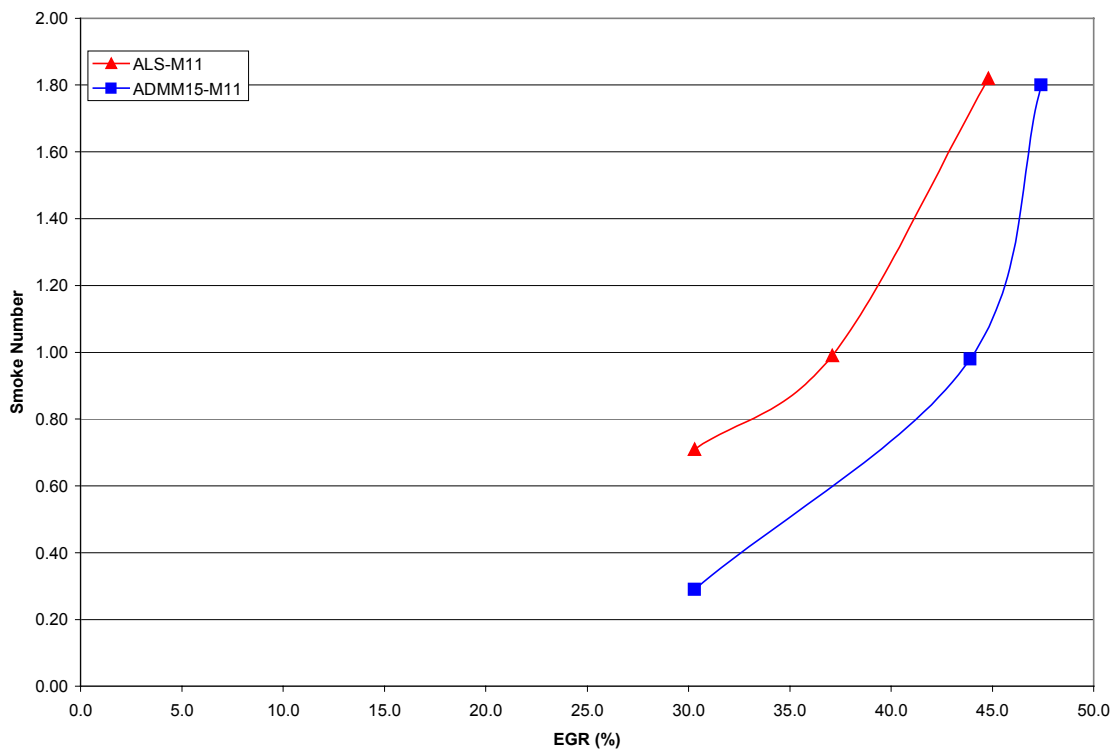
**Figure 8. NOx vs. PM Comparison Among Fuels**

The differences in NO<sub>x</sub> emissions among the fuels are small, although there are statistically significant differences between two groupings, with no difference between the DF-2 and ADMM15, while the CA, ALS and FT-100 being indistinguishable from each other.

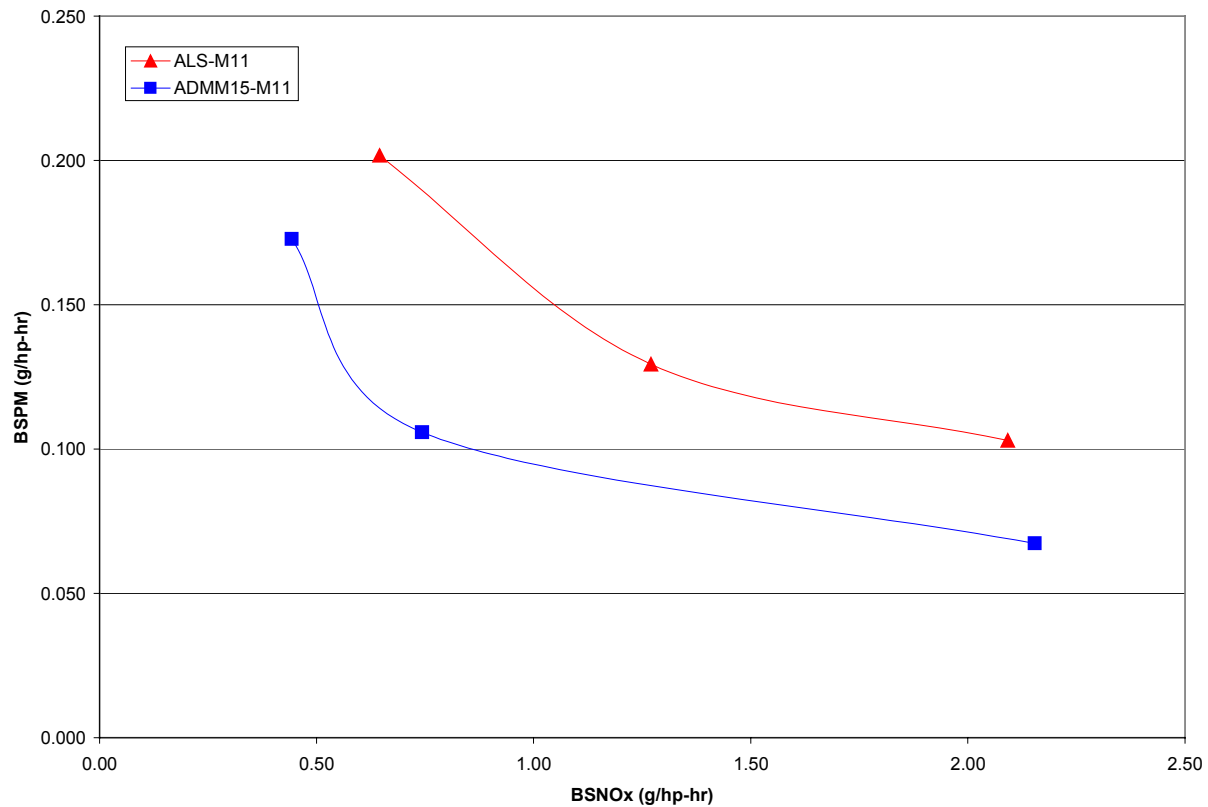
All these fuels were evaluated with the beginning of injection timing altered to achieve the best fuel economy timing for the individual fuel, but with no other control setting differences. The large PM reductions observed with two of the fuels raised the question of using increasing levels of EGR to reduce NO<sub>x</sub>, taking advantage of the lower PM emission. The sensitivity of the OM611 engine to

EGR, while operating at Location of Peak Pressure of 7°ATDC, was evaluated with the ADMM15 and ALS fuels by increasing EGR rate, starting from the Fuels Research group recommendations. Two modes of operation were chosen, Mode 11 (1500 RPM at 2.62 bar BMEP) and Mode 6 (2300 RPM/4.2 bar BMEP). The EGR sweeps were started at the Fuels Research group specified values of 30% for Mode 11, and 15% for Mode 6. A NO<sub>x</sub> instrument response versus AVL smoke number curve was generated. From those curves several points were selected for collecting PM filter samples.

For Mode 11 the points selected were 30% EGR, the EGR value that resulted in a smoke numbers of 1.0 and 1.8 for each fuel. The EGR versus smoke number results at Mode 11 for each fuel are shown in Figure 9. The data suggest ADMM15 allows higher EGR values to achieve the same smoke number. The corresponding PM-NO<sub>x</sub> curve shown in Figure 10 suggests the higher EGR rates associated with ADMM15 result in lower BSNO<sub>x</sub> emissions at the same BSPM emission level.



**Figure 9. EGR Impact on NO<sub>x</sub> at LPP7 °Timing, Mode 11**



**Figure 10. BSNO<sub>x</sub> vs. BSPM at LPP7 °Timing, Mode 11**

For Mode 6 the points selected were 15% EGR, and the corresponding EGR values for smoke numbers of 1.0 and 1.8 for each fuel. The EGR versus smoke number results at Mode 6 are shown in Figure 11. Mode 6 data also suggest ADMM15 allows higher EGR values to achieve the same smoke number. The PM-NO<sub>x</sub> curve shown in Figure 12 shows higher EGR rates associated with ADMM15 result in lower BSNO<sub>x</sub> emissions at the same BSPM emission level.

The overall conclusion with these data is that the beneficial PM reduction with oxygenated fuel can be “traded” for lower NO<sub>x</sub> emissions by increasing EGR.

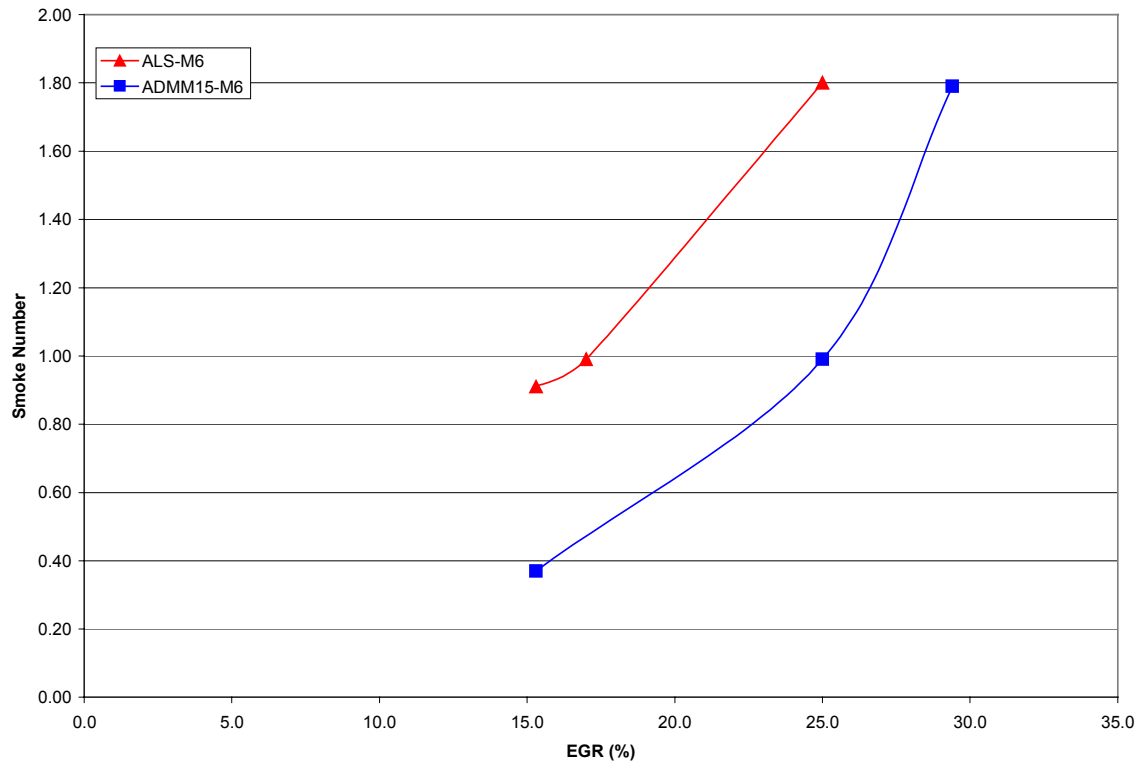


Figure 11. EGR Impact on Smoke Number, Mode 6

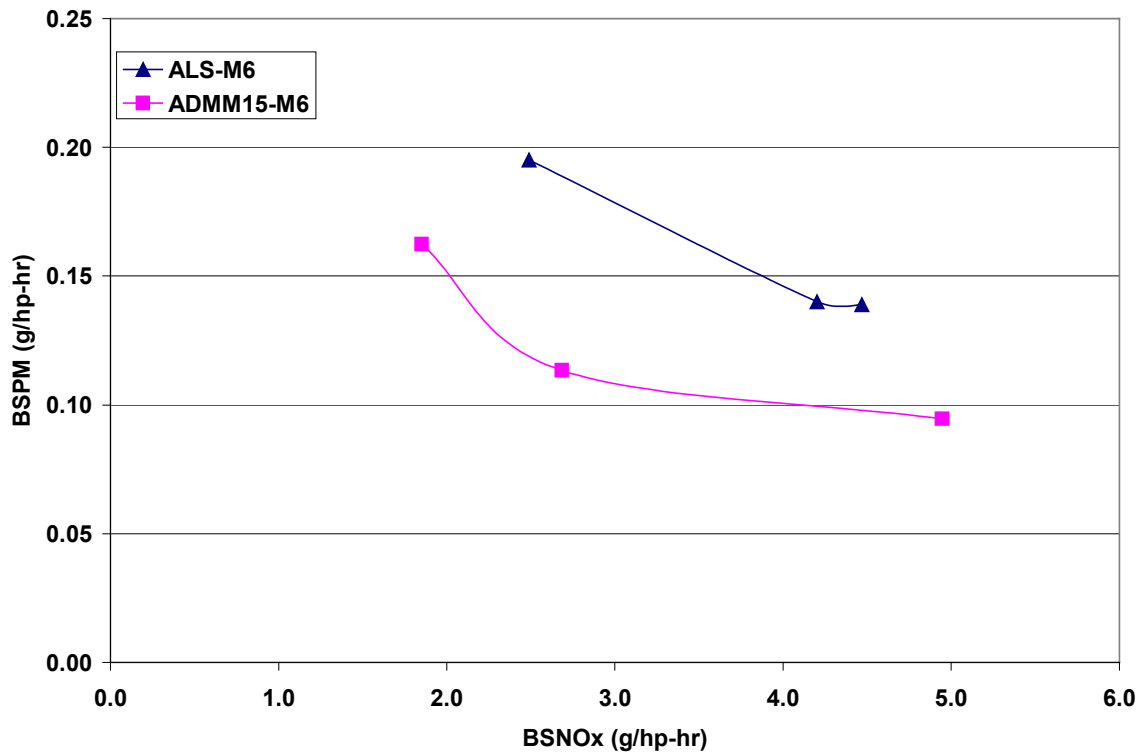


Figure 12. BSNOx vs. BSPPM at LPP7 °Timing, Mode 6

## 9.0 Conclusions

These results illustrate both the impact of engine control strategy on engine-out emissions, and the substantial impacts that changes in fuel formulation can have on engine-out particulate emissions. The results with ALS and ADMM15 indicate that the reduction in particulate, at least with oxygenated fuels, can allow increased levels of EGR in order to reduce the engine-out NO<sub>x</sub> emissions.

- For both Modes 0 and 11, using LPP = 7° timing, there was a 50% reduction in BSNO<sub>x</sub> (PM held constant) when using the oxygenated fuel, ADMM15, as compared to ALS.
- At a constant NO<sub>x</sub> level, there was a 42% decrease in BSPM for Mode 11 and a 30% decrease in BSPM for Mode 6 when using the oxygenated diesel fuel (ADMM15) as compared to ALS.

## 10.0 Recommendations

It is recommended that additional light-duty CIDI engine investigations be conducted to increase the knowledge and understanding of the complex interactions of PM and NO<sub>x</sub> tradeoff, alternative fuel effects, and engine operating parameters. Future considerations should include developing an overall strategy for meeting regulated NO<sub>x</sub> and PM emissions with a light-duty CIDI engine. The overall strategy should include engine operation parameters such as EGR rate, and injection timing, fuel composition effects, and exhaust after treatment devices.

## 11.0 References

- (1) Sirman, Melinda, Owens E. C. and Whitney, K. A., "Emissions Comparison of Alternative Fuels in an Advanced Automotive Diesel Engine," SAE Paper No. 2000-01-2048, June 2000.
- (2) Mann, Nic, Kvinge, Frode, and Wilson, Goeff, "Diesel Fuel Effects on Emissions: Towards a Better Understanding," SAE Paper No. 982486, 1998.
- (3) Atkinson, A.C. and Donev, A.N., Optimum Experimental Designs, 1992, Oxford University Press, New York.

**APPENDIX A**  
**Measured Parameters and Estimated Accuracy**



<b>Table A1. Analytical Emission Instrumentation</b>	
<b>Constituent</b>	<b>Analysis Method</b>
Total Hydrocarbon	Heated Flame Ionization Detector
Carbon Monoxide	Non-Dispersive Infrared Analysis
Carbon Dioxide	Non-Dispersive Infrared Analysis
Oxides of Nitrogen	Chemiluminescent Analysis
Particulate Matter	Gravimetric, CVS, CO <sub>2</sub> tracer

<b>Table A2. Measured Quantities</b>			
<b>Quantity</b>	<b>Description</b>	<b>Unit</b>	<b>Accuracy</b>
Engine Speed		rpm	+/- 4.2
Engine Load		ft-lb	+/- 2.3
Fuel Flow		lb/hr	+/- 5 %
Temp. Coolant In		°F	+/- 4
Temp. Coolant Out		°F	+/- 4
Temp. Oil		°F	+/- 4
Temp. Intake Air		°F	+/- 4
Temp. Fuel		°F	+/- 4
Temp. Exhaust		°F	+/- 25
Temp. Intercooler In		°F	+/- 4
Temp. Intercooler Out		°F	+/- 4
Temp. Air Dewpoint		°F	+/- 4
Pres. Ambient		"Hg	+/- 1%
Pres. Exh. Restriction		"Hg	+/- 1%
Pres. Boost Pre-Intercooler		"Hg	+/- 1%
Pres. Boost Post-Intercooler		"Hg	+/- 1%
Carbon Monoxide	CO	g/kW-hr	+/- 15 %
Hydrocarbon	HC	g/kW-hr	+/- 20 %
Nitric Oxides	NO <sub>x</sub>	g/kW-hr	+/- 10 %
Carbon Dioxide	CO <sub>2</sub>	g/kW-hr	+/- 10 %
Particulate (Total)	PM	g/kW-hr	+/- 20 %



## **Appendix B**

### **Example of Statistical Analysis of Engine Results for Fuel 2D, AL-25714-L.**



## Mode 05

PROJECT NAME: f2dm05.ecp  
Fuel 2D Mode 05

Centering Values:

EGR 7.640  
Boost Pressure 0.705  
Rail Pressure 875.160  
Inj Timing 7.000

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
2.52382				0 CONSTANT
-0.0992037	0.0502607	0.0767	0.220	1 EGR
1.23968	1.37956	0.3900	0.214	2 BoostPress
0.0021385	0.000531663	0.0024	0.842	3 RailPress
0.286274	0.0420704	0.0000	0.665	4 InjTiming
0.209015	0.594921	0.7326-	0.131	5 EGR*BoostPress
-0.000122285	0.000171418	0.4919-	0.524	6 EGR*RailPress
0.00503092	0.016899	0.7720-	0.339	7 EGR*InjTiming
0.00172955	0.00487878	0.7303-	0.524	8
BoostPress*RailPress				
0.0645974	0.372237	0.8657-	0.432	9
BoostPress*InjTiming				
0.000182465	0.000273528	0.5198-	0.916	10
RailPress*InjTiming				
-0.00308676	0.0139375	0.8292-	0.175	11 EGR^2
2.76988	10.2817	0.7931-	0.279	12 BoostPress^2
-1.10683e-005	1.15759e-005	0.3615-	0.688	13 RailPress^2
0.0442747	0.0359386	0.2461-	0.867	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.249326  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.466469

R Squared = 0.949, P=0.0001 \*\*\*  
Adj R Squared = 0.877  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
1.1237				0 CONSTANT
-0.0194008	0.0137222	0.1878	0.220	1 EGR
0.493111	0.37665	0.2197	0.214	2 BoostPress
-0.00146728	0.000145155	0.0000	0.842	3 RailPress
-0.102992	0.0114861	0.0000	0.665	4 InjTiming
-0.0707465	0.162426	0.6724-	0.131	5 EGR*BoostPress
-0.000100371	4.68006e-005	0.0576	0.524	6 EGR*RailPress
-0.00486568	0.00461378	0.3164	0.339	7 EGR*InjTiming
0.00202488	0.00133201	0.1594	0.524	8
BoostPress*RailPress				
0.0220564	0.101628	0.8325-	0.432	9
BoostPress*InjTiming				
0.000121231	7.46789e-005	0.1356	0.916	10
RailPress*InjTiming				
0.000779191	0.00380522	0.8419-	0.175	11 EGR^2
-1.06919	2.80713	0.7113-	0.279	12 BoostPress^2
6.98815e-007	3.16047e-006	0.8295-	0.688	13 RailPress^2
0.0106884	0.00981199	0.3016-	0.867	14 InjTiming^2

N trials = 25  
 N terms = 15  
  
 Residual SD = 0.068071  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.142030  
  
 R Squared = 0.967, P=0.0000 \*\*\*  
 Adj R Squared = 0.920  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.252306				0 CONSTANT
0.0237653	0.00896179	0.0242	0.220	1 EGR
-0.195039	0.245984	0.4462	0.214	2 BoostPress
-0.00104392	9.47987e-005	0.0000	0.842	3 RailPress
-0.0443851	0.0075014	0.0001	0.665	4 InjTiming
-0.0943677	0.106078	0.3946	0.131	5 EGR*BoostPress
-6.56191e-005	3.05648e-005	0.0574	0.524	6 EGR*RailPress
-0.00121606	0.00301319	0.6950-	0.339	7 EGR*InjTiming
0.00123104	0.000869916	0.1874	0.524	8
BoostPress*RailPress				
0.0370705	0.066372	0.5888-	0.432	9
BoostPress*InjTiming				
0.000195865	4.87717e-005	0.0025	0.916	10
RailPress*InjTiming				

0.00326031	0.00248513	0.2189	0.175	11	EGR^2
1.69206	1.83329	0.3778	0.279	12	BoostPress^2
1.0472e-007	2.06405e-006	0.9605-	0.688	13	RailPress^2
0.0086126	0.00640806	0.2086	0.867	14	InjTiming^2

N trials = 25  
 N terms = 15  
  
 Residual SD = 0.044456  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.081909  
  
 R Squared = 0.971, P=0.0000 \*\*\*  
 Adj R Squared = 0.931  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.390822				0 CONSTANT
0.00202751	0.00147922	0.2005	0.220	1 EGR
-0.034936	0.0406017	0.4097	0.214	2 BoostPress
-3.87606e-005	1.56473e-005	0.0327	0.842	3 RailPress
-0.00316329	0.00123817	0.0286	0.665	4 InjTiming
-0.0123587	0.017509	0.4964	0.131	5 EGR*BoostPress
1.9057e-006	5.04497e-006	0.7135-	0.524	6 EGR*RailPress
0.000201393	0.000497352	0.6941-	0.339	7 EGR*InjTiming
-2.74252e-005	0.000143587	0.8523-	0.524	8
BoostPress*RailPress				
0.00691643	0.0109552	0.5420-	0.432	9
BoostPress*InjTiming				
3.733e-006	8.05017e-006	0.6528-	0.916	10
RailPress*InjTiming				
0.000358415	0.000410192	0.4027	0.175	11 EGR^2
0.323698	0.3026	0.3099	0.279	12 BoostPress^2
-6.22115e-007	3.40689e-007	0.0978	0.688	13 RailPress^2
0.000649521	0.0010577	0.5529-	0.867	14 InjTiming^2

N trials = 25  
 N terms = 15  
  
 Residual SD = 0.007338  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.013404  
  
 R Squared = 0.781, P=0.0708  
 Adj R Squared = 0.475  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum absolute Studentized residual = 3.129 P=0.0000 \*\*\*  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
1.4182				0 CONSTANT
-0.0636731	0.0270635	0.0405	0.220	1 EGR
0.819453	0.742843	0.2958	0.214	2 BoostPress
0.00134644	0.000286281	0.0008	0.842	3 RailPress
0.171946	0.0226533	0.0000	0.665	4 InjTiming
0.161237	0.320343	0.6256-	0.131	5 EGR*BoostPress
-8.91323e-005	9.2302e-005	0.3570-	0.524	6 EGR*RailPress
0.000885331	0.00909948	0.9244-	0.339	7 EGR*InjTiming
0.00132149	0.00262704	0.6258-	0.524	8
BoostPress*RailPress				
0.0211008	0.200435	0.9182-	0.432	9
BoostPress*InjTiming				
0.000125172	0.000147285	0.4153-	0.916	10
RailPress*InjTiming				
-0.00301115	0.0075048	0.6967-	0.175	11 EGR^2
0.326464	5.53633	0.9541-	0.279	12 BoostPress^2
-3.37734e-006	6.23319e-006	0.5998-	0.688	13 RailPress^2
0.0243823	0.0193516	0.2363-	0.867	14 InjTiming^2

N trials = 25  
 N terms = 15

Residual SD = 0.134253  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.253108

R Squared = 0.958, P=0.0000 \*\*\*  
 Adj R Squared = 0.900  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'hc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.135143				0 CONSTANT
-0.00944562	0.00871638	0.3039	0.220	1 EGR
0.187131	0.239248	0.4522	0.214	2 BoostPress
3.95898e-005	9.22028e-005	0.6768-	0.842	3 RailPress
-0.00934543	0.00729598	0.2291	0.665	4 InjTiming
0.101884	0.103173	0.3467	0.131	5 EGR*BoostPress
-2.18988e-005	2.97278e-005	0.4783-	0.524	6 EGR*RailPress

-0.00499301	0.00293068	0.1193	0.339	7	EGR*InjTiming
-0.000206021	0.000846095	0.8125-	0.524	8	
BoostPress*RailPress					
-0.0189185	0.0645545	0.7755-	0.432	9	
BoostPress*InjTiming					
4.81782e-005	4.74361e-005	0.3337-	0.916	10	
RailPress*InjTiming					
-0.00247807	0.00241708	0.3294	0.175	11	EGR^2
-1.54357	1.78309	0.4070	0.279	12	BoostPress^2
1.19301e-006	2.00753e-006	0.5655-	0.688	13	RailPress^2
-0.00128632	0.00623259	0.8406-	0.867	14	InjTiming^2
N trials	=	25			
N terms	=	15			
Residual SD	=	0.043239			
Residual DF	=	10			
Residual SD used for tests					
Cross val RMS	=	0.080614			
R Squared	=	0.667, P=0.2894			
Adj R Squared	=	0.200	Maximum Cook-Weisberg LD influence (scaled 0-1)		
= 1.000					
- This term may be eliminated					

## Mode 06

PROJECT NAME: f2dm06.ecp  
Fuel 2D Mode 06

Centering Values:

EGR 9.250  
Boost Pressure 0.215  
Rail Pressure 625.205  
Inj Timing 4.000

NOTE: HC not modeled because of insufficient data.

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
1.89542				0 CONSTANT
-0.0574672	0.0177364	0.0089	0.346	1 EGR
-0.353878	1.23512	0.7803-	0.329	2 BoostPress
0.00253496	0.000430707	0.0002	0.785	3 RailPress
0.143596	0.0218753	0.0001	0.644	4 InjTiming
-0.064122	0.199725	0.7548-	0.296	5 EGR*BoostPress
-4.29623e-005	5.95686e-005	0.4873-	0.823	6 EGR*RailPress
-0.000953717	0.00285649	0.7454-	0.697	7 EGR*InjTiming
-0.00124647	0.00408676	0.7666-	0.858	8 BoostPress*RailPress
0.254614	0.175522	0.1775	0.862	9 BoostPress*InjTiming
0.0002143	0.000171916	0.2410	0.733	10 RailPress*InjTiming
0.0046918	0.00514477	0.3833	0.269	11 EGR^2
20.417	7.63327	0.0233	0.883	12 BoostPress^2
2.30932e-006	6.52632e-006	0.7308-	0.923	13 RailPress^2
-0.00211091	0.0125266	0.8695-	0.835	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.188295  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.463561

R Squared = 0.967, P=0.0000 \*\*\*  
Adj R Squared = 0.921  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
Maximum absolute Studentized residual = 2.689 P=0.0229 \*  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
3.64145				0 CONSTANT
-0.127059	0.0230711	0.0003	0.346	1 EGR
4.34934	1.60661	0.0220	0.329	2 BoostPress
-0.000437519	0.000560254	0.4529-	0.785	3 RailPress
-0.0927004	0.0284549	0.0086	0.644	4 InjTiming
0.483825	0.259798	0.0922	0.296	5 EGR*BoostPress
-0.000339909	7.74855e-005	0.0014	0.823	6 EGR*RailPress
-0.00924656	0.00371565	0.0321	0.697	7 EGR*InjTiming
0.00601603	0.00531596	0.2842-	0.858	8 BoostPress*RailPress
0.596495	0.228315	0.0259	0.862	9 BoostPress*InjTiming
0.000804633	0.000223624	0.0049	0.733	10 RailPress*InjTiming
-0.0163462	0.00669219	0.0347	0.269	11 EGR^2
-5.31409	9.92917	0.6042-	0.883	12 BoostPress^2
1.429e-006	8.48928e-006	0.8697-	0.923	13 RailPress^2
0.0513362	0.0162943	0.0103	0.835	14 InjTiming^2

N trials = 25

N terms = 15

Residual SD = 0.244929

Residual DF = 10

Residual SD used for tests

Cross val RMS = 0.558562

R Squared = 0.942, P=0.0002 \*\*\*

Adj R Squared = 0.862

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.52502				0 CONSTANT
0.00785263	0.00737222	0.3118	0.346	1 EGR
1.41785	0.513383	0.0201	0.329	2 BoostPress
-0.00204311	0.000179025	0.0000	0.785	3 RailPress
-0.0470515	0.00909259	0.0004	0.644	4 InjTiming
0.128738	0.0830168	0.1520	0.296	5 EGR*BoostPress
-0.000105218	2.476e-005	0.0017	0.823	6 EGR*RailPress
-0.00259472	0.00118731	0.0538	0.697	7 EGR*InjTiming
-0.00259103	0.00169868	0.1582	0.858	8 BoostPress*RailPress
-0.0956196	0.0729567	0.2193	0.862	9 BoostPress*InjTiming
0.000218047	7.14576e-005	0.0122	0.733	10 RailPress*InjTiming
-0.0020609	0.00213845	0.3579	0.269	11 EGR^2
-3.70771	3.1728	0.2697-	0.883	12 BoostPress^2
3.3355e-006	2.7127e-006	0.2470-	0.923	13 RailPress^2
0.0116884	0.00520673	0.0486	0.835	14 InjTiming^2

N trials = 25

N terms = 15

Residual SD = 0.078266  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.107441

R Squared = 0.973, P=0.0000 \*\*\*  
Adj R Squared = 0.936  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
Maximum absolute Studentized residual = 2.950 P=0.0007 \*\*\*  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.44619				0 CONSTANT
-0.000187521	0.000482659	0.7058-	0.346	1 EGR
0.0196376	0.0336111	0.5720-	0.329	2 BoostPress
-5.36979e-005	1.17208e-005	0.0010	0.785	3 RailPress
-0.00374505	0.000595291	0.0001	0.644	4 InjTiming
0.00548241	0.00543511	0.3369	0.296	5 EGR*BoostPress
5.79662e-007	1.62103e-006	0.7281-	0.823	6 EGR*RailPress
0.000102295	7.77332e-005	0.2176	0.697	7 EGR*InjTiming
0.00016785	0.000111213	0.1622	0.858	8 BoostPress*RailPress
0.00512606	0.00477647	0.3084-	0.862	9 BoostPress*InjTiming
1.50082e-005	4.67832e-006	0.0094	0.733	10 RailPress*InjTiming
-8.52137e-005	0.000140004	0.5563-	0.269	11 EGR^2
0.366183	0.207723	0.1084	0.883	12 BoostPress^2
4.30853e-007	1.776e-007	0.0357	0.923	13 RailPress^2
0.000149298	0.000340884	0.6707-	0.835	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.005124  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.012000

R Squared = 0.943, P=0.0002 \*\*\*  
Adj R Squared = 0.863  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
Maximum absolute Studentized residual = 2.788 P=0.0083 \*\*  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
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0.943785				0	CONSTANT
-0.0284292	0.00744528	0.0034	0.346	1	EGR
-0.193648	0.51847	0.7166-	0.329	2	BoostPress
0.00135811	0.0001808	0.0000	0.785	3	RailPress
0.0785495	0.0091827	0.0000	0.644	4	InjTiming
-0.0381679	0.0838395	0.6587-	0.296	5	EGR*BoostPress
-2.74266e-005	2.50054e-005	0.2984-	0.823	6	EGR*RailPress
-0.0010656	0.00119908	0.3950-	0.697	7	EGR*InjTiming
-0.00105892	0.00171551	0.5509-	0.858	8	BoostPress*RailPress
0.107494	0.0736797	0.1753	0.862	9	BoostPress*InjTiming
9.12669e-005	7.21657e-005	0.2347	0.733	10	RailPress*InjTiming
0.00231005	0.00215964	0.3099	0.269	11	EGR^2
8.73646	3.20425	0.0213	0.883	12	BoostPress^2
2.5819e-007	2.73958e-006	0.9268-	0.923	13	RailPress^2
-0.000404444	0.00525833	0.9402-	0.835	14	InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.079041  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.188516

R Squared = 0.978, P=0.0000 \*\*\*

Adj R Squared = 0.948

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum absolute Studentized residual = 2.627 P=0.0383 \*

- This term may be eliminated

## Mode 08

PROJECT NAME: f2dm08.ecp  
Fuel 2D Mode 08

Centering Values:

EGR 0.530  
Boost Pressure 0.900  
Rail Pressure 927.785  
Inj Timing 5.000

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
4.54377				0 CONSTANT
-0.124786	0.851461	0.8864-	0.248	1 EGR
3.05572	4.65149	0.5261	0.109	2 BoostPress
-0.00117948	0.0016593	0.4934-	0.495	3 RailPress
0.200152	0.0839263	0.0383	0.368	4 InjTiming
-7.94179	13.2071	0.5610-	0.111	5 EGR*BoostPress
-0.0103866	0.00479327	0.0555	0.492	6 EGR*RailPress
-0.264551	0.20097	0.2174	0.442	7 EGR*InjTiming
0.0179301	0.0110385	0.1354	0.640	8 BoostPress*RailPress
0.58032	0.423193	0.2003	0.645	9 BoostPress*InjTiming
-0.000474205	0.000557222	0.4147-	0.827	10 RailPress*InjTiming
-0.666154	2.55255	0.7994-	0.346	11 EGR^2
-25.1577	10.0559	0.0314	0.551	12 BoostPress^2
-2.03756e-005	2.98706e-005	0.5106-	0.797	13 RailPress^2
0.0496432	0.042931	0.2744-	0.801	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.275101  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.615896

R Squared = 0.960, P=0.0000 \*\*\*  
Adj R Squared = 0.904  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
2.93703				0 CONSTANT

-1.69347	7.55038	0.8270-	0.248	1 EGR
-11.5027	41.2474	0.7860-	0.109	2 BoostPress
0.0121936	0.014714	0.4266-	0.495	3 RailPress
-0.170015	0.744222	0.8239-	0.368	4 InjTiming
46.5875	117.115	0.6991-	0.111	5 EGR*BoostPress
0.0339316	0.0425046	0.4432-	0.492	6 EGR*RailPress
-0.42284	1.78212	0.8172-	0.442	7 EGR*InjTiming
-0.0716117	0.0978843	0.4812-	0.640	8 BoostPress*RailPress
2.722	3.75269	0.4849-	0.645	9 BoostPress*InjTiming
-0.00195199	0.0049412	0.7011-	0.827	10 RailPress*InjTiming
-0.299777	22.6349	0.9897-	0.346	11 EGR^2
167.018	89.1715	0.0906	0.551	12 BoostPress^2
-0.000134767	0.000264879	0.6219-	0.797	13 RailPress^2
-0.424103	0.380693	0.2913-	0.801	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 2.439478  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 3.517012

R Squared = 0.890, P=0.0041 \*\*  
Adj R Squared = 0.737  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.988  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.304631				0 CONSTANT
-0.951056	0.813115	0.2693	0.248	1 EGR
3.81341	4.44201	0.4107	0.109	2 BoostPress
0.00189777	0.00158457	0.2587	0.495	3 RailPress
0.0322562	0.0801467	0.6958-	0.368	4 InjTiming
18.132	12.6123	0.1811	0.111	5 EGR*BoostPress
0.00240025	0.0045774	0.6114-	0.492	6 EGR*RailPress
0.111974	0.191919	0.5725-	0.442	7 EGR*InjTiming
-0.0289692	0.0105413	0.0205	0.640	8 BoostPress*RailPress
0.0686534	0.404135	0.8685-	0.645	9 BoostPress*InjTiming
-0.000724062	0.000532127	0.2035	0.827	10 RailPress*InjTiming
-1.34652	2.4376	0.5928-	0.346	11 EGR^2
8.47123	9.60304	0.3984-	0.551	12 BoostPress^2
8.41521e-006	2.85253e-005	0.7740-	0.797	13 RailPress^2
-0.0796648	0.0409976	0.0807	0.801	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.262712

Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.519457

R Squared = 0.859, P=0.0123 \*  
 Adj R Squared = 0.661  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 - This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.363114				0 CONSTANT
-0.00130759	0.00637745	0.8417-	0.248	1 EGR
-0.116726	0.0348397	0.0074	0.109	2 BoostPress
-7.9909e-006	1.24282e-005	0.5347-	0.495	3 RailPress
-0.00456428	0.000628609	0.0000	0.368	4 InjTiming
0.130035	0.0989211	0.2180	0.111	5 EGR*BoostPress
1.04327e-005	3.59017e-005	0.7773-	0.492	6 EGR*RailPress
0.00207954	0.00150527	0.1972	0.442	7 EGR*InjTiming
-0.000162185	8.26783e-005	0.0782	0.640	8 BoostPress*RailPress
0.00226024	0.00316972	0.4921-	0.645	9 BoostPress*InjTiming
1.12602e-005	4.1736e-006	0.0224	0.827	10 RailPress*InjTiming
0.00412704	0.0191187	0.8334-	0.346	11 EGR^2
0.457566	0.0753189	0.0001	0.551	12 BoostPress^2
6.51934e-007	2.23731e-007	0.0155	0.797	13 RailPress^2
0.000205564	0.000321553	0.5370-	0.801	14 InjTiming^2

N trials = 25  
 N terms = 15

Residual SD = 0.002061  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.003798

R Squared = 0.996, P=0.0000 \*\*\*  
 Adj R Squared = 0.991  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 Maximum absolute Studentized residual = 2.657 P=0.0301 \*  
 - This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
2.74291				0 CONSTANT
-0.138995	0.491754	0.7832-	0.248	1 EGR
2.88637	2.68643	0.3079	0.109	2 BoostPress

-0.000600599	0.000958314	0.5449-	0.495	3 RailPress
0.15359	0.0484709	0.0100	0.368	4 InjTiming
-4.60185	7.62762	0.5597-	0.111	5 EGR*BoostPress
-0.00623173	0.00276831	0.0481	0.492	6 EGR*RailPress
-0.170639	0.116069	0.1723	0.442	7 EGR*InjTiming
0.0120138	0.00637517	0.0889	0.640	8 BoostPress*RailPress
0.511961	0.244411	0.0626	0.645	9 BoostPress*InjTiming
-0.000333475	0.000321819	0.3245-	0.827	10 RailPress*InjTiming
-0.537996	1.4742	0.7228-	0.346	11 EGR^2
-15.9355	5.8077	0.0207	0.551	12 BoostPress^2
-1.44223e-005	1.72515e-005	0.4227-	0.797	13 RailPress^2
0.0299892	0.0247944	0.2543-	0.801	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.158882  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.350355

R Squared = 0.974, P=0.0000 \*\*\*  
Adj R Squared = 0.938  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'hc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.0495763				0 CONSTANT
-0.0628678	0.152551	0.6899-	0.242	1 EGR
0.00686113	0.825786	0.9936-	0.109	2 BoostPress
0.000225939	0.000288387	0.4535-	0.495	3 RailPress
0.00329688	0.0149136	0.8300-	0.371	4 InjTiming
0.759499	2.34969	0.7539-	0.111	5 EGR*BoostPress
0.00040769	0.000832583	0.6361-	0.492	6 EGR*RailPress
0.0133837	0.0349352	0.7105-	0.457	7 EGR*InjTiming
-0.00129731	0.00193541	0.5195-	0.634	8 BoostPress*RailPress
-0.0982143	0.0736397	0.2151	0.670	9 BoostPress*InjTiming
6.35998e-005	9.69458e-005	0.5282-	0.825	10 RailPress*InjTiming
0.166267	0.452505	0.7218-	0.339	11 EGR^2
-2.47264	1.7592	0.1934	0.559	12 BoostPress^2
5.26384e-006	6.0554e-006	0.4073-	0.746	13 RailPress^2
-0.0078115	0.00745848	0.3223-	0.805	14 InjTiming^2

N trials = 24  
N terms = 15

Residual SD = 0.047784  
Residual DF = 9  
Residual SD used for tests

Cross val RMS = 0.078300

R Squared = 0.464, P=0.8432

Adj R Squared = 0.000

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

## Mode 10

PROJECT NAME: f2dm10.ecp  
Fuel 2D Mode 10

Centering Values:

EGR 22.005  
Rail Pressure 550.225  
Inj Timing 3.000

NOTE: HC not modeled because of insufficient data.  
Boost pressure was not included for Mode 10.

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
2.26454				0 CONSTANT
-0.110316	0.00370895	0.0000	0.949	1 EGR
0.0026158	0.000373052	0.0000	0.950	2 RailPress
0.255199	0.0115308	0.0000	0.922	3 InjTiming
-0.000140915	2.71654e-005	0.0004	0.933	4 EGR*RailPress
-0.010679	0.000821186	0.0000	0.918	5 EGR*InjTiming
0.00013384	8.45508e-005	0.1445	0.901	6 RailPress*InjTiming
0.00144859	0.0005345	0.0219	0.775	7 EGR^2
-1.21683e-005	5.59131e-006	0.0546	0.843	8 RailPress^2
0.0149763	0.0051656	0.0159	0.822	9 InjTiming^2

N trials = 20  
N terms = 10

Residual SD = 0.205612  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.301431

R Squared = 0.994, P=0.0000 \*\*\*  
Adj R Squared = 0.989  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.881

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
10.4675				0 CONSTANT
-0.115592	0.0869097	0.2130-	0.949	1 EGR
-0.00714891	0.00874152	0.4325-	0.950	2 RailPress
-0.646541	0.270195	0.0378	0.922	3 InjTiming
0.0002244	0.000636551	0.7318-	0.933	4 EGR*RailPress

0.00449712	0.0192424	0.8199-	0.918	5 EGR*InjTiming
0.00351378	0.00198123	0.1065	0.901	6 RailPress*InjTiming
0.00215765	0.0125246	0.8667-	0.775	7 EGR^2
-5.89757e-005	0.000131018	0.6622-	0.843	8 RailPress^2
0.134898	0.121042	0.2911-	0.822	9 InjTiming^2

N trials = 20  
N terms = 10

Residual SD = 4.817990  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 6.134478

R Squared = 0.615, P=0.1918  
Adj R Squared = 0.269  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
Maximum absolute Studentized residual = 3.040 P=0.0000 \*\*\*  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.353706				0 CONSTANT
-0.0126037	0.00821078	0.1558	0.949	1 EGR
-0.0019634	0.000825854	0.0388	0.950	2 RailPress
-0.0743918	0.0255266	0.0155	0.922	3 InjTiming
5.41328e-005	6.01381e-005	0.3892-	0.933	4 EGR*RailPress
0.00304018	0.00181792	0.1254	0.918	5 EGR*InjTiming
0.000297847	0.000187176	0.1426	0.901	6 RailPress*InjTiming
0.000101678	0.00118326	0.9332-	0.775	7 EGR^2
4.10807e-006	1.23779e-005	0.7468-	0.843	8 RailPress^2
0.0122705	0.0114355	0.3085-	0.822	9 InjTiming^2

N trials = 20  
N terms = 10

Residual SD = 0.455179  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.827839

R Squared = 0.757, P=0.0329 \*  
Adj R Squared = 0.539  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.606699				0 CONSTANT
0.00177916	0.000466844	0.0034	0.949	1 EGR
-0.000196258	4.6956e-005	0.0019	0.950	2 RailPress
-0.0127436	0.00145138	0.0000	0.922	3 InjTiming
-6.97447e-006	3.4193e-006	0.0687	0.933	4 EGR*RailPress
-0.000379757	0.000103362	0.0043	0.918	5 EGR*InjTiming
4.8284e-005	1.06424e-005	0.0011	0.901	6 RailPress*InjTiming
-4.92688e-005	6.72773e-005	0.4808	0.775	7 EGR^2
1.14864e-006	7.03777e-007	0.1337	0.843	8 RailPress^2
0.00185454	0.000650192	0.0172	0.822	9 InjTiming^2

N trials = 20  
N terms = 10

Residual SD = 0.025880  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.054625

R Squared = 0.955, P=0.0000 \*\*\*  
Adj R Squared = 0.915  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.828454				0 CONSTANT
-0.0400482	0.00113999	0.0000	0.949	1 EGR
0.000960899	0.000114662	0.0000	0.950	2 RailPress
0.100702	0.00354415	0.0000	0.922	3 InjTiming
-4.91189e-005	8.34964e-006	0.0002	0.933	4 EGR*RailPress
-0.00404005	0.000252402	0.0000	0.918	5 EGR*InjTiming
2.058e-005	2.59878e-005	0.4468	0.901	6 RailPress*InjTiming
0.000464772	0.000164285	0.0179	0.775	7 EGR^2
-4.65968e-006	1.71856e-006	0.0219	0.843	8 RailPress^2
0.0053811	0.00158771	0.0069	0.822	9 InjTiming^2

N trials = 20  
N terms = 10

Residual SD = 0.063198  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.084601

R Squared = 0.996, P=0.0000 \*\*\*  
Adj R Squared = 0.993

Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.367  
- This term may be eliminated

## Mode 11

PROJECT NAME: f2dm11.ecp  
Fuel 2D Mode 11

Centering Values:

EGR 29.820  
Rail Pressure 543.705  
Inj Timing 2.000

NOTE: HC not modeled because of insufficient data.  
Boost pressure was not included in Mode 11.

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
4.47875				0 CONSTANT
-0.186258	0.0849476	0.0597	0.572	1 EGR
0.00568341	0.00397422	0.1906	0.784	2 RailPress
0.179614	0.172114	0.3272-	0.604	3 InjTiming
0.00012877	0.000361205	0.7307-	0.718	4 EGR*RailPress
-0.0088371	0.0158106	0.5915-	0.622	5 EGR*InjTiming
0.000401916	0.000679561	0.5706-	0.828	6 RailPress*InjTiming
-0.00649095	0.00814807	0.4487-	0.794	7 EGR^2
-0.000123924	3.87243e-005	0.0126	0.752	8 RailPress^2
0.0909736	0.0457695	0.0821	0.716	9 InjTiming^2

N trials = 18  
N terms = 10

Residual SD = 2.242470  
Residual DF = 8  
Residual SD used for tests  
Cross val RMS = 4.030432

R Squared = 0.749, P=0.0919  
Adj R Squared = 0.467  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
2.51853				0 CONSTANT
0.0623241	0.0424309	0.1801	0.572	1 EGR
-0.00810725	0.0019851	0.0035	0.784	2 RailPress
-0.131539	0.0859698	0.1645	0.604	3 InjTiming

-0.000310792	0.00018042	0.1233	0.718	4	EGR*RailPress
0.00598248	0.00789733	0.4705-	0.622	5	EGR*InjTiming
0.00116425	0.000339437	0.0090	0.828	6	RailPress*InjTiming
0.00294921	0.00406992	0.4893-	0.794	7	EGR^2
1.68086e-005	1.93426e-005	0.4102-	0.752	8	RailPress^2
0.0589897	0.0228616	0.0326	0.716	9	InjTiming^2

N trials = 18

N terms = 10

Residual SD = 1.120101

Residual DF = 8

Residual SD used for tests

Cross val RMS = 1.746135

R Squared = 0.858, P=0.0134 \*

Adj R Squared = 0.699

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.313071				0 CONSTANT
0.015848	0.0208881	0.4698-	0.572	1 EGR
-0.000821975	0.000977237	0.4247-	0.784	2 RailPress
0.035534	0.0423218	0.4255-	0.604	3 InjTiming
-5.07543e-005	8.88184e-005	0.5834-	0.718	4 EGR*RailPress
0.00466578	0.00388775	0.2644	0.622	5 EGR*InjTiming
-8.32118e-005	0.0001671	0.6319-	0.828	6 RailPress*InjTiming
0.000293379	0.00200357	0.8872-	0.794	7 EGR^2
9.56825e-006	9.52209e-006	0.3444-	0.752	8 RailPress^2
-0.0016644	0.0112545	0.8861-	0.716	9 InjTiming^2

N trials = 18

N terms = 10

Residual SD = 0.551411

Residual DF = 8

Residual SD used for tests

Cross val RMS = 0.750874

R Squared = 0.478, P=0.6205

Adj R Squared = 0.000

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.502881				0 CONSTANT
0.000292749	0.000567489	0.6199-	0.572	1 EGR
-5.23886e-005	2.65496e-005	0.0839	0.784	2 RailPress
-0.00221664	0.0011498	0.0900	0.604	3 InjTiming
-1.01529e-006	2.41302e-006	0.6850-	0.718	4 EGR*RailPress
3.77519e-005	0.000105622	0.7300-	0.622	5 EGR*InjTiming
6.36534e-006	4.53977e-006	0.1985	0.828	6 RailPress*InjTiming
-5.31148e-005	5.44328e-005	0.3577-	0.794	7 EGR^2
6.27451e-007	2.58696e-007	0.0415	0.752	8 RailPress^2
-0.000173492	0.000305761	0.5860-	0.716	9 InjTiming^2

N trials = 18  
N terms = 10

Residual SD = 0.014981  
Residual DF = 8  
Residual SD used for tests  
Cross val RMS = 0.027979

R Squared = 0.716, P=0.1348  
Adj R Squared = 0.397  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
1.97692				0 CONSTANT
-0.0828264	0.0368919	0.0550	0.572	1 EGR
0.00254574	0.00172596	0.1785	0.784	2 RailPress
0.0851073	0.0747472	0.2878	0.604	3 InjTiming
5.34626e-005	0.000156868	0.7420-	0.718	4 EGR*RailPress
-0.00391216	0.0068664	0.5845-	0.622	5 EGR*InjTiming
0.000169222	0.000295126	0.5821-	0.828	6 RailPress*InjTiming
-0.00288753	0.00353863	0.4381-	0.794	7 EGR^2
-5.50514e-005	1.68176e-005	0.0113	0.752	8 RailPress^2
0.0403809	0.0198773	0.0767	0.716	9 InjTiming^2

N trials = 18  
N terms = 10

Residual SD = 0.973882  
Residual DF = 8  
Residual SD used for tests  
Cross val RMS = 1.692684

R Squared = 0.759, P=0.0807  
Adj R Squared = 0.488

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

## Mode 12

PROJECT NAME: f2dm12.ecp  
Fuel 2D Mode 12

Centering Values:

EGR 25.360  
Rail Pressure 326.100  
Inj Timing 4.000

NOTE: HC not modeled because of insufficient data.  
Boost Pressure was not included for Mode 12.

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
32.989				0 CONSTANT
-0.925902	0.0439156	0.0000	0.890	1 EGR
0.102355	0.0133346	0.0000	0.917	2 RailPress
2.83651	0.166489	0.0000	0.917	3 InjTiming
-0.00261078	0.000620466	0.0018	0.893	4 EGR*RailPress
-0.0972683	0.00751002	0.0000	0.922	5 EGR*InjTiming
0.00382835	0.00236121	0.1360	0.926	6 RailPress*InjTiming
-0.00623262	0.00428834	0.1768	0.728	7 EGR^2
-0.000932981	0.000399084	0.0415	0.815	8 RailPress^2
0.122107	0.0631092	0.0818	0.805	9 InjTiming^2

N trials = 20  
N terms = 10

Residual SD = 3.540243  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 8.104420

R Squared = 0.990, P=0.0000 \*\*\*  
Adj R Squared = 0.981  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
Maximum absolute Studentized residual = 2.656 P=0.0243 \*

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
250.346				0 CONSTANT
0.432878	0.711909	0.5567-	0.890	1 EGR
-0.375794	0.216165	0.1128	0.917	2 RailPress
-4.02947	2.69892	0.1663	0.917	3 InjTiming

0.0267014	0.0100583	0.0241	0.893	4 EGR*RailPress
0.246296	0.121744	0.0706	0.922	5 EGR*InjTiming
0.0897434	0.0382772	0.0410	0.926	6 RailPress*InjTiming
-0.00860833	0.0695175	0.9039-	0.728	7 EGR^2
-0.00271225	0.00646949	0.6839-	0.815	8 RailPress^2
2.32828	1.02305	0.0461	0.805	9 InjTiming^2

N trials = 20  
N terms = 10

Residual SD = 57.390264  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 122.431677

R Squared = 0.758, P=0.0326 \*  
Adj R Squared = 0.540  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
13.7156				0 CONSTANT
0.218104	0.329011	0.5224-	0.890	1 EGR
-0.201075	0.0999014	0.0718	0.917	2 RailPress
-5.62995	1.24731	0.0011	0.917	3 InjTiming
0.00735845	0.00464846	0.1445	0.893	4 EGR*RailPress
-0.0327032	0.0562642	0.5739-	0.922	5 EGR*InjTiming
0.0364236	0.0176899	0.0665	0.926	6 RailPress*InjTiming
-0.00678959	0.0321277	0.8369-	0.728	7 EGR^2
0.00270033	0.00298989	0.3877-	0.815	8 RailPress^2
0.484656	0.472807	0.3295-	0.805	9 InjTiming^2

N trials = 20  
N terms = 10

Residual SD = 26.523085  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 44.407446

R Squared = 0.812, P=0.0111 \*  
Adj R Squared = 0.643  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
Maximum absolute Studentized residual = 2.678 P=0.0201 \*  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
4.36282				0 CONSTANT
0.00893858	0.0108567	0.4295-	0.890	1 EGR
-0.00339202	0.00329656	0.3277-	0.917	2 RailPress
-0.113586	0.0411591	0.0201	0.917	3 InjTiming
0.000149797	0.000153391	0.3518-	0.893	4 EGR*RailPress
-0.00107555	0.00185661	0.5752-	0.922	5 EGR*InjTiming
0.000810448	0.000583735	0.1952	0.926	6 RailPress*InjTiming
0.000720217	0.00106015	0.5123-	0.728	7 EGR^2
-2.05637e-005	9.86609e-005	0.8391-	0.815	8 RailPress^2
0.0247178	0.0156018	0.1442	0.805	9 InjTiming^2

N trials = 20  
N terms = 10

Residual SD = 0.875213  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 1.331247

R Squared = 0.674, P=0.1056  
Adj R Squared = 0.381  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.898  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
1.58449				0 CONSTANT
-0.0427673	0.0023803	0.0000	0.890	1 EGR
0.00526273	0.000722758	0.0000	0.917	2 RailPress
0.134778	0.00902397	0.0000	0.917	3 InjTiming
-0.000139208	3.36303e-005	0.0020	0.893	4 EGR*RailPress
-0.00474312	0.000407056	0.0000	0.922	5 EGR*InjTiming
8.44513e-005	0.000127982	0.5242-	0.926	6 RailPress*InjTiming
-0.000460582	0.000232435	0.0757	0.728	7 EGR^2
-1.16413e-005	2.1631e-005	0.6022-	0.815	8 RailPress^2
0.000874356	0.00342063	0.8034-	0.805	9 InjTiming^2

N trials = 20  
N terms = 10

Residual SD = 0.191887  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.308475

R Squared = 0.987, P=0.0000 \*\*\*

Adj R Squared = 0.975

Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.986

- This term may be eliminated

## Mode 16

PROJECT NAME: f2dml6.ecp

Fuel 2D Mode 16

Centering Values:

EGR 6.105  
Boost Pressure 1.000  
Rail Pressure 1273.775  
Inj Timing 14.000

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
4.31631				0 CONSTANT
-0.235613	0.0137442	0.0000	0.774	1 EGR
2.92932	0.663166	0.0013	0.787	2 BoostPress
0.00442171	0.000786781	0.0002	0.876	3 RailPress
0.286586	0.028909	0.0000	0.878	4 InjTiming
0.139465	0.230548	0.5587-	0.558	5 EGR*BoostPress
0.000156593	0.000182998	0.4122-	0.867	6 EGR*RailPress
-0.0234535	0.0068421	0.0065	0.857	7 EGR*InjTiming
0.0088942	0.0088563	0.3389-	0.879	8 BoostPress*RailPress
1.05703	0.333984	0.0101	0.851	9 BoostPress*InjTiming
-0.000558963	0.000432087	0.2249-	0.905	10 RailPress*InjTiming
-0.00408357	0.0055791	0.4810-	0.606	11 EGR^2
-37.7474	12.6146	0.0135	0.845	12 BoostPress^2
1.9904e-005	2.18915e-005	0.3846-	0.859	13 RailPress^2
0.0210663	0.0329358	0.5368-	0.858	14 InjTiming^2

N trials = 25

N terms = 15

Residual SD = 0.226133

Residual DF = 10

Residual SD used for tests

Cross val RMS = 0.493654

R Squared = 0.982, P=0.0000 \*\*\*

Adj R Squared = 0.956

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.992832				0 CONSTANT

0.102312	0.0186089	0.0003	0.774	1 EGR
-3.01773	0.897889	0.0072	0.787	2 BoostPress
-0.00280508	0.00106526	0.0250	0.876	3 RailPress
-0.108708	0.0391412	0.0195	0.878	4 InjTiming
-0.44285	0.31215	0.1864	0.558	5 EGR*BoostPress
-0.000137535	0.000247769	0.5910-	0.867	6 EGR*RailPress
-0.00119383	0.00926382	0.9000-	0.857	7 EGR*InjTiming
0.00883283	0.0119909	0.4783-	0.879	8 BoostPress*RailPress
0.0355336	0.452195	0.9389-	0.851	9 BoostPress*InjTiming
0.000575444	0.000585021	0.3485-	0.905	10 RailPress*InjTiming
0.00648535	0.00755378	0.4107-	0.606	11 EGR^2
7.71439	17.0794	0.6611-	0.845	12 BoostPress^2
-3.77912e-006	2.96399e-005	0.9011-	0.859	13 RailPress^2
-0.0058743	0.0445932	0.8978-	0.858	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.306172  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.455200

R Squared = 0.833, P=0.0250 \*  
Adj R Squared = 0.598  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.952  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.407635				0 CONSTANT
0.0564023	0.00484486	0.0000	0.774	1 EGR
-1.20179	0.233767	0.0004	0.787	2 BoostPress
-0.00230236	0.000277342	0.0000	0.876	3 RailPress
-0.0628866	0.0101905	0.0001	0.878	4 InjTiming
-0.187372	0.0812687	0.0438	0.558	5 EGR*BoostPress
-0.000354597	6.4507e-005	0.0003	0.867	6 EGR*RailPress
-0.00748847	0.00241185	0.0112	0.857	7 EGR*InjTiming
0.00387847	0.00312186	0.2424-	0.879	8 BoostPress*RailPress
-0.151901	0.11773	0.2260-	0.851	9 BoostPress*InjTiming
0.000319843	0.000152311	0.0621	0.905	10 RailPress*InjTiming
0.00593863	0.00196664	0.0129	0.606	11 EGR^2
1.28568	4.44665	0.7784-	0.845	12 BoostPress^2
-6.32197e-007	7.71679e-006	0.9363-	0.859	13 RailPress^2
0.00273961	0.0116099	0.8182-	0.858	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.079712

Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.152981

R Squared = 0.963, P=0.0000 \*\*\*  
 Adj R Squared = 0.910  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.409179				0 CONSTANT
0.00189532	0.000261466	0.0000	0.774	1 EGR
-0.0631051	0.0126159	0.0005	0.787	2 BoostPress
-6.53912e-005	1.49675e-005	0.0014	0.876	3 RailPress
-0.00541299	0.000549956	0.0000	0.878	4 InjTiming
-0.00681	0.00438589	0.1515	0.558	5 EGR*BoostPress
6.29597e-007	3.48129e-006	0.8601-	0.867	6 EGR*RailPress
3.09823e-005	0.000130162	0.8167-	0.857	7 EGR*InjTiming
0.000166523	0.00016848	0.3463-	0.879	8 BoostPress*RailPress
-0.00652804	0.00635361	0.3284-	0.851	9 BoostPress*InjTiming
5.18095e-006	8.21989e-006	0.5426-	0.905	10 RailPress*InjTiming
0.000139711	0.000106135	0.2174	0.606	11 EGR^2
-0.00922584	0.239976	0.9701-	0.845	12 BoostPress^2
1.01094e-007	4.16458e-007	0.8131-	0.859	13 RailPress^2
0.000373885	0.00062656	0.5640-	0.858	14 InjTiming^2

N trials = 25  
 N terms = 15

Residual SD = 0.004302  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.008075

R Squared = 0.944, P=0.0002 \*\*\*  
 Adj R Squared = 0.867  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.998  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
2.32606				0 CONSTANT
-0.136708	0.00750104	0.0000	0.774	1 EGR
1.9249	0.361929	0.0003	0.787	2 BoostPress
0.00270862	0.000429393	0.0001	0.876	3 RailPress

0.183602	0.0157774	0.0000	0.878	4 InjTiming
0.0882303	0.125824	0.4992-	0.558	5 EGR*BoostPress
5.43508e-005	9.98727e-005	0.5982-	0.867	6 EGR*RailPress
-0.0149671	0.00373414	0.0025	0.857	7 EGR*InjTiming
0.00438214	0.00483341	0.3859-	0.879	8 BoostPress*RailPress
0.633178	0.182275	0.0060	0.851	9 BoostPress*InjTiming
-0.000284797	0.000235815	0.2549-	0.905	10 RailPress*InjTiming
-0.00237305	0.00304484	0.4538-	0.606	11 EGR^2
-19.7884	6.88451	0.0165	0.845	12 BoostPress^2
1.00706e-005	1.19475e-005	0.4190-	0.859	13 RailPress^2
0.0114438	0.017975	0.5387-	0.858	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.123414  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.275920

R Squared = 0.984, P=0.0000 \*\*\*  
Adj R Squared = 0.963  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'hc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.014017				0 CONSTANT
0.000153388	0.000481781	0.7567-	0.774	1 EGR
0.00401969	0.0232462	0.8662-	0.787	2 BoostPress
-1.47278e-006	2.75793e-005	0.9585-	0.876	3 RailPress
0.0022763	0.00101336	0.0485	0.878	4 InjTiming
0.00541753	0.00808148	0.5178-	0.558	5 EGR*BoostPress
-1.97441e-006	6.41467e-006	0.7646-	0.867	6 EGR*RailPress
0.000512467	0.000239838	0.0584	0.857	7 EGR*InjTiming
-0.000148349	0.000310443	0.6430-	0.879	8 BoostPress*RailPress
-0.0117541	0.0117072	0.3391-	0.851	9 BoostPress*InjTiming
1.03353e-005	1.51461e-005	0.5105-	0.905	10 RailPress*InjTiming
0.00017383	0.000195566	0.3950-	0.606	11 EGR^2
-0.128651	0.442182	0.7770-	0.845	12 BoostPress^2
1.5637e-006	7.6737e-007	0.0689	0.859	13 RailPress^2
0.00185687	0.00115451	0.1388	0.858	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.007927  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.015458

R Squared = 0.708, P=0.1935  
Adj R Squared = 0.299  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

## Mode 17

PROJECT NAME: f2dm17.ecp  
Fuel 2D Mode 17

Centering Values:

EGR 2.985  
Boost Pressure 1.220  
Rail Pressure 1091.315  
Inj Timing 9.500

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
3.84342				0 CONSTANT
-0.590216	0.174909	0.0071	0.147	1 EGR
12.6922	5.19241	0.0346	0.135	2 BoostPress
0.000137524	0.00330252	0.9676-	0.316	3 RailPress
0.118388	0.144259	0.4310	0.253	4 InjTiming
7.11035	2.34178	0.0125	0.172	5 EGR*BoostPress
0.000423802	0.00245282	0.8663-	0.160	6 EGR*RailPress
-0.109743	0.141096	0.4547	0.117	7 EGR*InjTiming
-0.016825	0.0645656	0.7997-	0.171	8 BoostPress*RailPress
2.95099	3.29489	0.3915	0.154	9 BoostPress*InjTiming
0.000306919	0.00108236	0.7825-	0.531	10 RailPress*InjTiming
-0.108097	0.0846647	0.2305	0.158	11 EGR^2
-163.619	59.6046	0.0207	0.300	12 BoostPress^2
2.42942e-005	5.37127e-005	0.6607-	0.249	13 RailPress^2
0.117714	0.0768881	0.1568	0.795	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.244520  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.686041

R Squared = 0.923, P=0.0009 \*\*\*  
Adj R Squared = 0.814  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
Maximum absolute Studentized residual = 2.821 P=0.0056 \*\*  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'hc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
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0.0373206				0	CONSTANT
0.00324855	0.00745954	0.6725-	0.147	1	EGR
-0.0915673	0.221446	0.6880-	0.135	2	BoostPress
-4.03957e-005	0.000140846	0.7801-	0.316	3	RailPress
-0.00705239	0.00615236	0.2784	0.253	4	InjTiming
0.0595916	0.0998722	0.5640-	0.172	5	EGR*BoostPress
-5.94818e-005	0.000104608	0.5822-	0.160	6	EGR*RailPress
-0.00516721	0.00601747	0.4106	0.117	7	EGR*InjTiming
0.00146469	0.0027536	0.6064-	0.171	8	BoostPress*RailPress
0.176258	0.14052	0.2383	0.154	9	BoostPress*InjTiming
6.7034e-006	4.61604e-005	0.8874-	0.531	10	RailPress*InjTiming
-0.00103371	0.00361078	0.7805-	0.158	11	EGR^2
-1.86385	2.54202	0.4803-	0.300	12	BoostPress^2
-1.41951e-006	2.29074e-006	0.5493-	0.249	13	RailPress^2
0.00536182	0.00327913	0.1331	0.795	14	InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.010428  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.037718

R Squared = 0.670, P=0.2815  
Adj R Squared = 0.207  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
1.02042				0 CONSTANT
0.361107	0.0558741	0.0001	0.147	1 EGR
-11.4564	1.6587	0.0000	0.135	2 BoostPress
0.0023634	0.00105498	0.0490	0.316	3 RailPress
0.083195	0.046083	0.1012	0.253	4 InjTiming
-3.6856	0.748071	0.0006	0.172	5 EGR*BoostPress
-0.00173061	0.000783546	0.0517	0.160	6 EGR*RailPress
0.0982843	0.0450726	0.0542	0.117	7 EGR*InjTiming
0.049266	0.0206252	0.0380	0.171	8 BoostPress*RailPress
-3.14934	1.05254	0.0135	0.154	9 BoostPress*InjTiming
0.000869953	0.000345755	0.0306	0.531	10 RailPress*InjTiming
0.0710102	0.0270458	0.0254	0.158	11 EGR^2
72.7476	19.0405	0.0034	0.300	12 BoostPress^2
-4.98865e-005	1.71583e-005	0.0156	0.249	13 RailPress^2
0.0122982	0.0245616	0.6274-	0.795	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.078111  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.351977

R Squared = 0.949, P=0.0001 \*\*\*  
 Adj R Squared = 0.878  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 - This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.313993				0 CONSTANT
-0.0328236	0.0478155	0.5080	0.147	1 EGR
3.12645	1.41946	0.0522	0.135	2 BoostPress
-0.00417123	0.00090282	0.0010	0.316	3 RailPress
0.0264645	0.0394365	0.5174-	0.253	4 InjTiming
0.698766	0.640178	0.3006	0.172	5 EGR*BoostPress
-0.00109981	0.000670536	0.1320	0.160	6 EGR*RailPress
0.0446995	0.0385718	0.2734	0.117	7 EGR*InjTiming
0.0220516	0.0176505	0.2400	0.171	8 BoostPress*RailPress
-1.19855	0.900733	0.2129	0.154	9 BoostPress*InjTiming
0.00010691	0.000295887	0.7254-	0.531	10 RailPress*InjTiming
0.0365886	0.023145	0.1450	0.158	11 EGR^2
-47.0653	16.2943	0.0161	0.300	12 BoostPress^2
2.89558e-005	1.46836e-005	0.0769	0.249	13 RailPress^2
-0.0364048	0.0210191	0.1139	0.795	14 InjTiming^2

N trials = 25  
 N terms = 15

Residual SD = 0.066845  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.259597

R Squared = 0.959, P=0.0000 \*\*\*  
 Adj R Squared = 0.901  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 - This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.378574				0 CONSTANT
0.00133557	0.00175443	0.4641	0.147	1 EGR
-0.05529	0.0520826	0.3134	0.135	2 BoostPress

-3.60415e-005	3.3126e-005	0.3021	0.316	3 RailPress
-0.00337721	0.00144699	0.0418	0.253	4 InjTiming
-0.0276853	0.0234893	0.2658	0.172	5 EGR*BoostPress
1.12894e-005	2.46031e-005	0.6561-	0.160	6 EGR*RailPress
0.00042329	0.00141527	0.7710-	0.117	7 EGR*InjTiming
-0.000244989	0.000647628	0.7131-	0.171	8 BoostPress*RailPress
0.000441271	0.0330495	0.9896-	0.154	9 BoostPress*InjTiming
4.817e-006	1.08566e-005	0.6667-	0.531	10 RailPress*InjTiming
0.00063921	0.000849232	0.4690	0.158	11 EGR^2
0.397412	0.597866	0.5213-	0.300	12 BoostPress^2
-1.43002e-007	5.38767e-007	0.7961-	0.249	13 RailPress^2
0.000331239	0.000771228	0.6767-	0.795	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.002453  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.006123

R Squared = 0.920, P=0.0010 \*\*\*  
Adj R Squared = 0.808  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
2.23559				0 CONSTANT
-0.358612	0.098931	0.0047	0.147	1 EGR
7.86236	2.93689	0.0232	0.135	2 BoostPress
0.000284729	0.00186795	0.8819-	0.316	3 RailPress
0.0873787	0.0815947	0.3094	0.253	4 InjTiming
4.39198	1.32454	0.0078	0.172	5 EGR*BoostPress
0.000228312	0.00138735	0.8726-	0.160	6 EGR*RailPress
-0.0705172	0.0798057	0.3977	0.117	7 EGR*InjTiming
-0.0098096	0.0365191	0.7937-	0.171	8 BoostPress*RailPress
1.79978	1.86363	0.3569	0.154	9 BoostPress*InjTiming
0.000190039	0.000612194	0.7626-	0.531	10 RailPress*InjTiming
-0.0694643	0.0478874	0.1775	0.158	11 EGR^2
-98.2384	33.7131	0.0155	0.300	12 BoostPress^2
1.60725e-005	3.03806e-005	0.6083-	0.249	13 RailPress^2
0.0675243	0.0434889	0.1515	0.795	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.138304  
Residual DF = 10  
Residual SD used for tests

Cross val RMS = 0.389534

R Squared = 0.935, P=0.0004 \*\*\*

Adj R Squared = 0.845

Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000

Maximum absolute Studentized residual = 2.803 P=0.0069 \*\*

- This term may be eliminated

## Mode 18

PROJECT NAME: f2dml8.ecp  
Fuel 2D Mode 18

Centering Values:

EGR 0.115  
Boost Pressure 0.585  
Rail Pressure 801.395  
Inj Timing 5.000

NOTE: HC not modeled because of insufficient data.

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
3.47165				0 CONSTANT
1.95592	3.83402	0.6210-	0.329	1 EGR
30.7679	14.5366	0.0604	0.224	2 BoostPress
-4.35858e-005	0.000685718	0.9506-	0.680	3 RailPress
0.152624	0.0575775	0.0243	0.324	4 InjTiming
62.0764	154.874	0.6970-	0.257	5 EGR*BoostPress
0.01961	0.0165314	0.2629	0.359	6 EGR*RailPress
1.32966	0.868831	0.1569	0.280	7 EGR*InjTiming
-0.0064484	0.0243331	0.7964-	0.704	8 BoostPress*RailPress
3.05447	1.04981	0.0156	0.665	9 BoostPress*InjTiming
-0.000356887	0.00023306	0.1567	0.448	10 RailPress*InjTiming
-11.2655	26.4175	0.6788-	0.681	11 EGR^2
202.844	304.464	0.5203-	0.537	12 BoostPress^2
-2.04108e-005	7.80857e-006	0.0259	0.664	13 RailPress^2
-0.0190908	0.0122235	0.1494	0.680	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.415602  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.876005

R Squared = 0.828, P=0.0281 \*  
Adj R Squared = 0.586  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
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55.428				0	CONSTANT
-581.588	334.745	0.1130	0.329	1	EGR
-2796.08	1269.18	0.0522	0.224	2	BoostPress
0.0154071	0.0598696	0.8021-	0.680	3	RailPress
-10.299	5.02705	0.0677	0.324	4	InjTiming
-22872.3	13521.9	0.1216	0.257	5	EGR*BoostPress
-0.99146	1.44334	0.5077-	0.359	6	EGR*RailPress
-88.9705	75.857	0.2680	0.280	7	EGR*InjTiming
2.52909	2.12451	0.2614-	0.704	8	BoostPress*RailPress
-114.571	91.6581	0.2398	0.665	9	BoostPress*InjTiming
0.0223637	0.0203483	0.2975	0.448	10	RailPress*InjTiming
-80.4488	2306.49	0.9729-	0.681	11	EGR^2
-45343.2	26582.6	0.1189	0.537	12	BoostPress^2
6.21492e-005	0.000681761	0.9292-	0.664	13	RailPress^2
1.53118	1.06722	0.1819	0.680	14	InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 36.285897  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 68.336824

R Squared = 0.659, P=0.3085  
Adj R Squared = 0.182  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
-5.16054				0 CONSTANT
-43.7057	25.9404	0.1229	0.329	1 EGR
-245.251	98.3529	0.0318	0.224	2 BoostPress
-0.00877511	0.00463948	0.0879	0.680	3 RailPress
-0.969732	0.389561	0.0320	0.324	4 InjTiming
-1397.6	1047.85	0.2119	0.257	5 EGR*BoostPress
-0.179552	0.111849	0.1395	0.359	6 EGR*RailPress
-12.5909	5.87839	0.0579	0.280	7 EGR*InjTiming
0.122713	0.164635	0.4732-	0.704	8 BoostPress*RailPress
-10.1905	7.10286	0.1819	0.665	9 BoostPress*InjTiming
0.00288833	0.00157685	0.0969	0.448	10 RailPress*InjTiming
-56.8476	178.737	0.7570-	0.681	11 EGR^2
-320.695	2059.96	0.8794-	0.537	12 BoostPress^2
0.000144391	5.28317e-005	0.0211	0.664	13 RailPress^2
0.208259	0.0827024	0.0305	0.680	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 2.811904  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 5.649905

R Squared = 0.811, P=0.0402 \*  
 Adj R Squared = 0.547  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.33377				0 CONSTANT
-0.499402	0.257524	0.0812	0.329	1 EGR
-2.75182	0.9764	0.0182	0.224	2 BoostPress
-2.35746e-005	4.60585e-005	0.6199-	0.680	3 RailPress
-0.00923873	0.00386738	0.0380	0.324	4 InjTiming
-15.5389	10.4026	0.1661	0.257	5 EGR*BoostPress
-0.00212744	0.00111038	0.0844	0.359	6 EGR*RailPress
-0.130253	0.0583578	0.0497	0.280	7 EGR*InjTiming
0.000990994	0.00163441	0.5578-	0.704	8 BoostPress*RailPress
-0.156162	0.0705138	0.0512	0.665	9 BoostPress*InjTiming
3.69761e-005	1.56542e-005	0.0398	0.448	10 RailPress*InjTiming
-1.13707	1.77442	0.5361-	0.681	11 EGR^2
-4.81386	20.4503	0.8187-	0.537	12 BoostPress^2
1.66675e-006	5.24488e-007	0.0099	0.664	13 RailPress^2
0.00230071	0.000821029	0.0187	0.680	14 InjTiming^2

N trials = 25  
 N terms = 15

Residual SD = 0.027915  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.054965

R Squared = 0.807, P=0.0436 \*  
 Adj R Squared = 0.538  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
2.00633				0 CONSTANT
1.94121	2.73875	0.4946-	0.329	1 EGR

21.407	10.3839	0.0662	0.224	2 BoostPress
-4.21721e-005	0.000489829	0.9331-	0.680	3 RailPress
0.0969462	0.0411293	0.0402	0.324	4 InjTiming
51.5043	110.631	0.6515-	0.257	5 EGR*BoostPress
0.0139959	0.0118088	0.2633	0.359	6 EGR*RailPress
0.879809	0.620631	0.1867	0.280	7 EGR*InjTiming
-0.00713849	0.0173819	0.6900-	0.704	8 BoostPress*RailPress
2.10162	0.749909	0.0187	0.665	9 BoostPress*InjTiming
-0.000266906	0.000166482	0.1400	0.448	10 RailPress*InjTiming
-3.57148	18.8708	0.8537-	0.681	11 EGR^2
126.586	217.488	0.5734-	0.537	12 BoostPress^2
-1.45434e-005	5.57789e-006	0.0262	0.664	13 RailPress^2
-0.0141192	0.00873159	0.1369	0.680	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.296877  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.625217

R Squared = 0.805, P=0.0461 \*  
Adj R Squared = 0.531  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

## Mode 19

PROJECT NAME: f2dml9.ecp  
Fuel 2D Mode 19

Centering Values:

EGR 3.340  
Boost Pressure 0.225  
Rail Pressure 737.430  
Inj Timing 5.000

NOTE: HC not modeled because of insufficient data.

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
3.87994				0 CONSTANT
-0.289434	0.0564512	0.0004	0.530	1 EGR
5.32736	6.06812	0.4006	0.276	2 BoostPress
0.00404935	0.000611653	0.0001	0.658	3 RailPress
0.422833	0.044683	0.0000	0.564	4 InjTiming
-2.16657	2.01602	0.3078	0.302	5 EGR*BoostPress
-0.00023581	0.000212459	0.2930-	0.709	6 EGR*RailPress
-0.0186557	0.0150893	0.2446	0.608	7 EGR*InjTiming
0.018341	0.0104732	0.1105	0.888	8 BoostPress*RailPress
0.848228	0.833713	0.3329-	0.714	9 BoostPress*InjTiming
0.00013558	0.000171525	0.4476-	0.875	10 RailPress*InjTiming
0.073447	0.0316812	0.0429	0.551	11 EGR^2
97.826	95.1421	0.3281-	0.507	12 BoostPress^2
-2.22627e-006	6.1538e-006	0.7250-	0.776	13 RailPress^2
0.00275422	0.0220535	0.9031-	0.848	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.336552  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.505651

R Squared = 0.981, P=0.0000 \*\*\*  
Adj R Squared = 0.956  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.996  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
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1.75896				0	CONSTANT
0.1835	0.15405	0.2611	0.530	1	EGR
-29.2527	16.5594	0.1078	0.276	2	BoostPress
0.00581901	0.00166915	0.0059	0.658	3	RailPress
-0.24323	0.121936	0.0740	0.564	4	InjTiming
-4.38716	5.50154	0.4437-	0.302	5	EGR*BoostPress
0.00126545	0.000579782	0.0540	0.709	6	EGR*RailPress
-0.0420091	0.0411774	0.3317-	0.608	7	EGR*InjTiming
-0.069468	0.0285805	0.0354	0.888	8	BoostPress*RailPress
0.947985	2.27513	0.6857-	0.714	9	BoostPress*InjTiming
0.000104006	0.000468077	0.8286-	0.875	10	RailPress*InjTiming
-0.0996158	0.0864552	0.2760	0.551	11	EGR^2
-144.776	259.634	0.5894-	0.507	12	BoostPress^2
3.33925e-005	1.67932e-005	0.0748	0.776	13	RailPress^2
0.00871149	0.060182	0.8878-	0.848	14	InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.918421  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 1.451886

R Squared = 0.879, P=0.0063 \*\*  
Adj R Squared = 0.710  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.531  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.285108				0 CONSTANT
0.0431715	0.0218521	0.0764	0.530	1 EGR
-0.693729	2.34896	0.7738-	0.276	2 BoostPress
-0.000615103	0.00023677	0.0266	0.658	3 RailPress
-0.0521578	0.0172967	0.0130	0.564	4 InjTiming
0.292352	0.780397	0.7158-	0.302	5 EGR*BoostPress
4.30631e-005	8.22424e-005	0.6120-	0.709	6 EGR*RailPress
-0.0103653	0.00584105	0.1064	0.608	7 EGR*InjTiming
0.0053692	0.00405416	0.2149	0.888	8 BoostPress*RailPress
0.0978213	0.322728	0.7680-	0.714	9 BoostPress*InjTiming
8.82883e-005	6.6397e-005	0.2131	0.875	10 RailPress*InjTiming
0.00376592	0.0122637	0.7651-	0.551	11 EGR^2
23.0116	36.8293	0.5461-	0.507	12 BoostPress^2
3.4193e-006	2.38212e-006	0.1817	0.776	13 RailPress^2
-0.0102501	0.00853686	0.2575-	0.848	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.130279  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.269043

R Squared = 0.878, P=0.0065 \*\*  
 Adj R Squared = 0.708  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 Maximum absolute Studentized residual = 2.992 P=0.0003 \*\*\*  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.373742				0 CONSTANT
0.00152798	0.00112341	0.2037	0.530	1 EGR
-0.143768	0.120759	0.2613	0.276	2 BoostPress
1.33241e-005	1.21722e-005	0.2993-	0.658	3 RailPress
-0.00230218	0.000889214	0.0270	0.564	4 InjTiming
0.0107598	0.0401198	0.7940-	0.302	5 EGR*BoostPress
5.17183e-006	4.22804e-006	0.2493	0.709	6 EGR*RailPress
-6.57974e-005	0.000300285	0.8310-	0.608	7 EGR*InjTiming
2.18022e-006	0.000208422	0.9919-	0.888	8 BoostPress*RailPress
0.000612108	0.0165913	0.9713-	0.714	9 BoostPress*InjTiming
7.54264e-006	3.41343e-006	0.0516	0.875	10 RailPress*InjTiming
-0.000159217	0.000630472	0.8057-	0.551	11 EGR^2
-0.278393	1.89337	0.8860-	0.507	12 BoostPress^2
2.04292e-007	1.22464e-007	0.1262	0.776	13 RailPress^2
-7.86961e-005	0.000438875	0.8613-	0.848	14 InjTiming^2

N trials = 25  
 N terms = 15

Residual SD = 0.006698  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.012135

R Squared = 0.822, P=0.0319 \*  
 Adj R Squared = 0.573  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 Maximum absolute Studentized residual = 2.641 P=0.0343 \*  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

2.28025				0	CONSTANT
-0.177994	0.0384692	0.0009	0.530	1	EGR
4.21775	4.13518	0.3318	0.276	2	BoostPress
0.00226446	0.000416817	0.0003	0.658	3	RailPress
0.262155	0.0304497	0.0000	0.564	4	InjTiming
-1.466	1.37384	0.3110	0.302	5	EGR*BoostPress
-0.000182157	0.000144782	0.2369	0.709	6	EGR*RailPress
-0.0135938	0.0102828	0.2156	0.608	7	EGR*InjTiming
0.011723	0.00713708	0.1315	0.888	8	BoostPress*RailPress
0.651272	0.568142	0.2784-	0.714	9	BoostPress*InjTiming
2.19521e-005	0.000116887	0.8548-	0.875	10	RailPress*InjTiming
0.0470061	0.0215895	0.0545	0.551	11	EGR^2
69.3327	64.8355	0.3100	0.507	12	BoostPress^2
-3.12718e-006	4.19357e-006	0.4730-	0.776	13	RailPress^2
0.0033805	0.0150286	0.8266-	0.848	14	InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.229347  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.352147

R Squared = 0.977, P=0.0000 \*\*\*  
Adj R Squared = 0.946  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

## Mode 20

PROJECT NAME: f2dml9.ecp  
Fuel 2D Mode 20

Centering Values:

EGR 10.895  
Boost Pressure 0.010  
Rail Pressure 551.460  
Inj Timing 3.000

NOTE: HC not modeled because of insufficient data.

«xxxxxxxxxxxx» Coefficients for response 'nox'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
3.87994				0 CONSTANT
-0.289434	0.0564512	0.0004	0.530	1 EGR
5.32736	6.06812	0.4006	0.276	2 BoostPress
0.00404935	0.000611653	0.0001	0.658	3 RailPress
0.422833	0.044683	0.0000	0.564	4 InjTiming
-2.16657	2.01602	0.3078	0.302	5 EGR*BoostPress
-0.00023581	0.000212459	0.2930-	0.709	6 EGR*RailPress
-0.0186557	0.0150893	0.2446	0.608	7 EGR*InjTiming
0.018341	0.0104732	0.1105	0.888	8 BoostPress*RailPress
0.848228	0.833713	0.3329-	0.714	9 BoostPress*InjTiming
0.00013558	0.000171525	0.4476-	0.875	10 RailPress*InjTiming
0.073447	0.0316812	0.0429	0.551	11 EGR^2
97.826	95.1421	0.3281-	0.507	12 BoostPress^2
-2.22627e-006	6.1538e-006	0.7250-	0.776	13 RailPress^2
0.00275422	0.0220535	0.9031-	0.848	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.336552  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.505651

R Squared = 0.981, P=0.0000 \*\*\*  
Adj R Squared = 0.956  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.996  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'co'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

1.75896				0	CONSTANT
0.1835	0.15405	0.2611	0.530	1	EGR
-29.2527	16.5594	0.1078	0.276	2	BoostPress
0.00581901	0.00166915	0.0059	0.658	3	RailPress
-0.24323	0.121936	0.0740	0.564	4	InjTiming
-4.38716	5.50154	0.4437-	0.302	5	EGR*BoostPress
0.00126545	0.000579782	0.0540	0.709	6	EGR*RailPress
-0.0420091	0.0411774	0.3317-	0.608	7	EGR*InjTiming
-0.069468	0.0285805	0.0354	0.888	8	BoostPress*RailPress
0.947985	2.27513	0.6857-	0.714	9	BoostPress*InjTiming
0.000104006	0.000468077	0.8286-	0.875	10	RailPress*InjTiming
-0.0996158	0.0864552	0.2760	0.551	11	EGR^2
-144.776	259.634	0.5894-	0.507	12	BoostPress^2
3.33925e-005	1.67932e-005	0.0748	0.776	13	RailPress^2
0.00871149	0.060182	0.8878-	0.848	14	InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.918421  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 1.451886

R Squared = 0.879, P=0.0063 \*\*  
Adj R Squared = 0.710  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 0.531  
- This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'pm'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.285108				0 CONSTANT
0.0431715	0.0218521	0.0764	0.530	1 EGR
-0.693729	2.34896	0.7738-	0.276	2 BoostPress
-0.000615103	0.00023677	0.0266	0.658	3 RailPress
-0.0521578	0.0172967	0.0130	0.564	4 InjTiming
0.292352	0.780397	0.7158-	0.302	5 EGR*BoostPress
4.30631e-005	8.22424e-005	0.6120-	0.709	6 EGR*RailPress
-0.0103653	0.00584105	0.1064	0.608	7 EGR*InjTiming
0.0053692	0.00405416	0.2149	0.888	8 BoostPress*RailPress
0.0978213	0.322728	0.7680-	0.714	9 BoostPress*InjTiming
8.82883e-005	6.6397e-005	0.2131	0.875	10 RailPress*InjTiming
0.00376592	0.0122637	0.7651-	0.551	11 EGR^2
23.0116	36.8293	0.5461-	0.507	12 BoostPress^2
3.4193e-006	2.38212e-006	0.1817	0.776	13 RailPress^2
-0.0102501	0.00853686	0.2575-	0.848	14 InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.130279  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.269043

R Squared = 0.878, P=0.0065 \*\*  
 Adj R Squared = 0.708  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 Maximum absolute Studentized residual = 2.992 P=0.0003 \*\*\*  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'bsfc'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
0.373742				0 CONSTANT
0.00152798	0.00112341	0.2037	0.530	1 EGR
-0.143768	0.120759	0.2613	0.276	2 BoostPress
1.33241e-005	1.21722e-005	0.2993-	0.658	3 RailPress
-0.00230218	0.000889214	0.0270	0.564	4 InjTiming
0.0107598	0.0401198	0.7940-	0.302	5 EGR*BoostPress
5.17183e-006	4.22804e-006	0.2493	0.709	6 EGR*RailPress
-6.57974e-005	0.000300285	0.8310-	0.608	7 EGR*InjTiming
2.18022e-006	0.000208422	0.9919-	0.888	8 BoostPress*RailPress
0.000612108	0.0165913	0.9713-	0.714	9 BoostPress*InjTiming
7.54264e-006	3.41343e-006	0.0516	0.875	10 RailPress*InjTiming
-0.000159217	0.000630472	0.8057-	0.551	11 EGR^2
-0.278393	1.89337	0.8860-	0.507	12 BoostPress^2
2.04292e-007	1.22464e-007	0.1262	0.776	13 RailPress^2
-7.86961e-005	0.000438875	0.8613-	0.848	14 InjTiming^2

N trials = 25  
 N terms = 15

Residual SD = 0.006698  
 Residual DF = 10  
 Residual SD used for tests  
 Cross val RMS = 0.012135

R Squared = 0.822, P=0.0319 \*  
 Adj R Squared = 0.573  
 Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
 Maximum absolute Studentized residual = 2.641 P=0.0343 \*  
 - This term may be eliminated

«xxxxxxxxxxxx» Coefficients for response 'noxindex'

Centered continuous variables

COEFFICIENTS	SD	P	CONDITION	TERM
--------------	----	---	-----------	------

2.28025				0	CONSTANT
-0.177994	0.0384692	0.0009	0.530	1	EGR
4.21775	4.13518	0.3318	0.276	2	BoostPress
0.00226446	0.000416817	0.0003	0.658	3	RailPress
0.262155	0.0304497	0.0000	0.564	4	InjTiming
-1.466	1.37384	0.3110	0.302	5	EGR*BoostPress
-0.000182157	0.000144782	0.2369	0.709	6	EGR*RailPress
-0.0135938	0.0102828	0.2156	0.608	7	EGR*InjTiming
0.011723	0.00713708	0.1315	0.888	8	BoostPress*RailPress
0.651272	0.568142	0.2784-	0.714	9	BoostPress*InjTiming
2.19521e-005	0.000116887	0.8548-	0.875	10	RailPress*InjTiming
0.0470061	0.0215895	0.0545	0.551	11	EGR^2
69.3327	64.8355	0.3100	0.507	12	BoostPress^2
-3.12718e-006	4.19357e-006	0.4730-	0.776	13	RailPress^2
0.0033805	0.0150286	0.8266-	0.848	14	InjTiming^2

N trials = 25  
N terms = 15

Residual SD = 0.229347  
Residual DF = 10  
Residual SD used for tests  
Cross val RMS = 0.352147

R Squared = 0.977, P=0.0000 \*\*\*  
Adj R Squared = 0.946  
Maximum Cook-Weisberg LD influence (scaled 0-1) = 1.000  
- This term may be eliminated

**Appendix C**  
**Analysis of Variance for the LPP procedure**

Analysis of Variance was conducted for the LPP procedure results for modes \*\*\*\*\* for each of the gaseous and particulate emissions. Because of the variability of the engine results at mode 12, this mode was excluded from the above analysis and conducted separately.



Multifactor ANOVA - Total Particulates (g/kW-hr)  
LPP Only Modes 5,6,10,11

Analysis Summary

Dependent variable: PARTIC

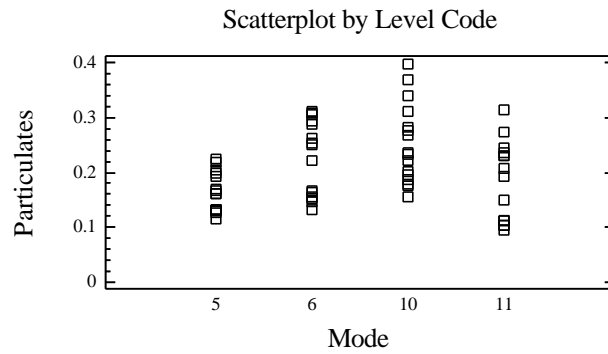
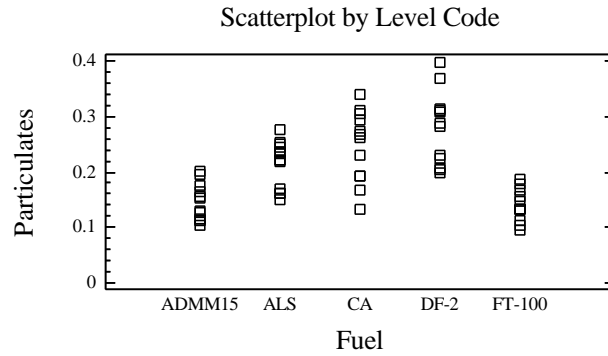
Factors:

FUEL

MODE

Selection variable: MODE < 12

Number of complete cases: 62

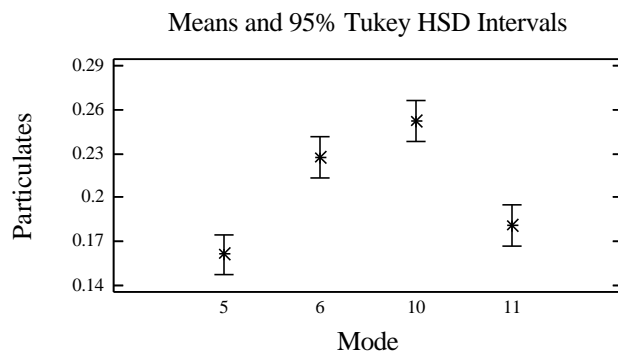


Analysis of Variance for PARTIC - Type III Sums of Squares

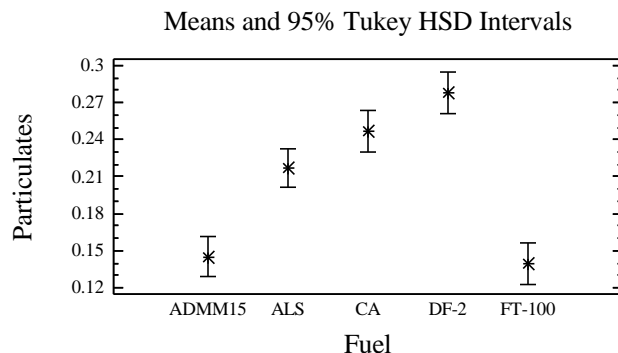
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	0.180096	4	0.0450239	55.43	0.0000
B:MODE	0.0812661	3	0.0270887	33.35	0.0000
INTERACTIONS					
AB	0.0203674	12	0.00169728	2.09	0.0392
RESIDUAL	0.0341148	42	0.000812257		
TOTAL (CORRECTED)	0.31392	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average particulates among the fuels, modes, and fuel\*mode interaction.



CONCLUSION: Average particulate at Modes 5 and 11 are not significantly different from one another. Average particulate at Modes 6 and 10 are not significantly different from one another. Average particulate at modes 5 and 11 are significantly different than modes 6 and 10.



CONCLUSION: Average particulate at fuels FT-100 and ADMM15 are not significantly different from one another, but are different than the other 3 fuels. The average particulate at Fuel ALS is significantly different than Fuel DF-2. The CA fuel is not significantly different than either the ALS or DF-2 fuel.

#### Multiple Range Tests for PARTIC by MODE

Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
5	16	0.161392	X
11	15	0.180949	X
6	15	0.227259	X
10	16	0.252179	X

Contrast	Difference	+/- Limits
5 - 6	*-0.0658665	0.0274018
5 - 10	*-0.0907872	0.0269563
5 - 11	-0.0195566	0.0274018
6 - 10	-0.0249207	0.0274018
6 - 11	*0.04631	0.0278403
10 - 11	*0.0712306	0.0274018

\* denotes a statistically significant difference.

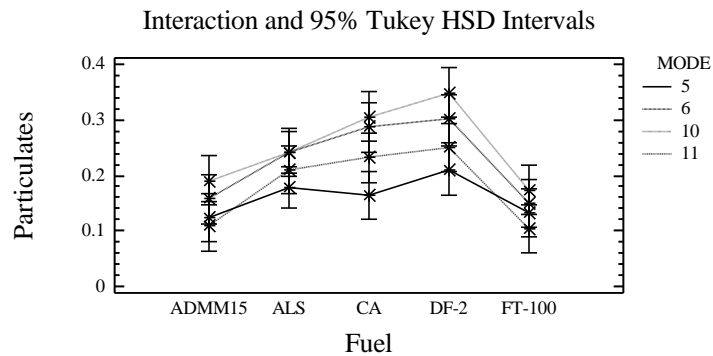
#### Multiple Range Tests for PARTIC by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	0.13969	X
ADMM15	12	0.145389	X
ALS	14	0.217693	X
CA	12	0.247083	XX
DF-2	12	0.277368	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*-0.0723034	0.0319542
ADMM15 - CA	*-0.101694	0.0331604
ADMM15 - DF-2	*-0.131979	0.0331604
ADMM15 - FT-100	0.00569934	0.0331604
ALS - CA	-0.0293907	0.0319542
ALS - DF-2	*-0.0596755	0.0319542
ALS - FT-100	*0.0780028	0.0319542
CA - DF-2	-0.0302847	0.0331604
CA - FT-100	*0.107394	0.0331604
DF-2 - FT-100	*0.137678	0.0331604

\* denotes a statistically significant difference.



CONCLUSION: The CA and DF-2 fuels have significantly different average particulate at Modes 5 and 11 than at modes 6 and 10. All other fuels do not demonstrate significant differences in the average particulate among the four modes.

Multifactor ANOVA - BSSOF (g/kW-hr)  
LPP Only Modes 5,6,10,11

#### Analysis Summary

Dependent variable: bssof

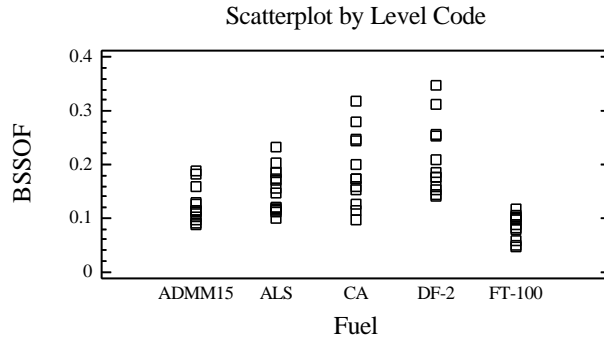
Factors:

fuel

mode

Selection variable: mode<12

Number of complete cases: 61

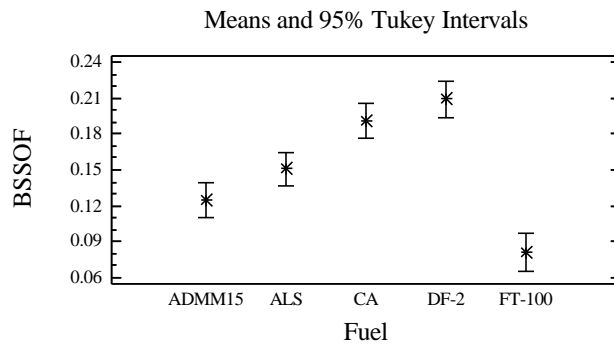


#### Analysis of Variance for bssof - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A: fuel	0.119091	4	0.0297726	47.06	0.0000
B: mode	0.0867779	3	0.028926	45.73	0.0000
INTERACTIONS					
AB	0.0319369	12	0.0026614	4.21	0.0003
RESIDUAL	0.025936	41	0.000632586		
TOTAL (CORRECTED)	0.25938	60			

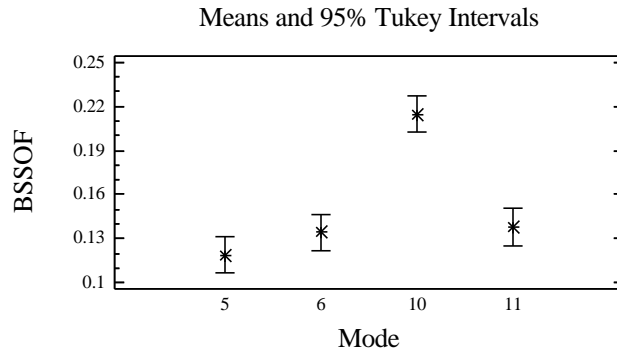
All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average BSSOF among the fuels, modes, and fuel\*mode interaction.



CONCLUSION: There are three distinct fuel groupings with respect to the average

BSSOF. The FT-100 fuel is significantly different from the remaining four fuels. The DF-2 and CA fuels are not significantly different from one another, but are different from the other three fuels. Also, the ALS and ADMM15 fuels are not significantly different from one another, but are different from the other three fuels.



CONCLUSION: The average BSSOF for mode 10 is significantly different from the remaining three modes. The average BSSOF for modes 5, 6, and 11 are not significantly different from one another.

Multiple Range Tests for bssof by fuel

Method: 95.0 percent Tukey HSD			
fuel	Count	LS Mean	Homogeneous Groups
FT-100	11	0.0812057	X
ADMM15	12	0.125126	X
ALS	14	0.151043	X
CA	12	0.190591	X
DF-2	12	0.209108	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.0259175	0.0282299
ADMM15 - CA	*-0.0654649	0.0292956
ADMM15 - DF-2	*-0.0839822	0.0292956
ADMM15 - FT-100	*0.04392	0.029954
ALS - CA	*-0.0395474	0.0282299
ALS - DF-2	*-0.0580647	0.0282299
ALS - FT-100	*0.0698376	0.0289126
CA - DF-2	-0.0185173	0.0292956
CA - FT-100	*0.109385	0.029954
DF-2 - FT-100	*0.127902	0.029954

\* denotes a statistically significant difference.

Multiple Range Tests for bssof by mode

Method: 95.0 percent Tukey HSD			
mode	Count	LS Mean	Homogeneous Groups
5	16	0.118924	X
6	15	0.13431	X
11	14	0.137743	X
10	16	0.214683	X

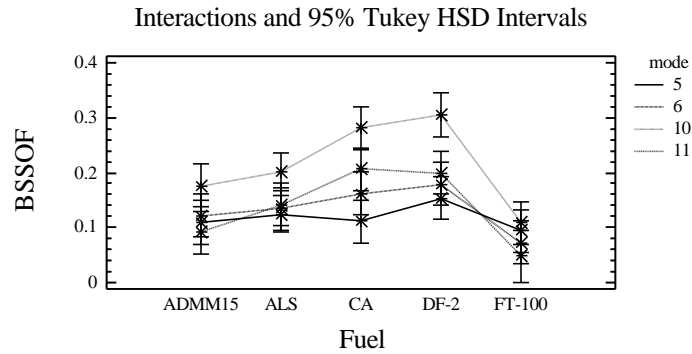
  

Contrast	Difference	+/- Limits
5 - 6	-0.0153858	0.0242062
5 - 10	*-0.0957587	0.0238126

5 - 11	-0.0188186	0.0246484
6 - 10	*-0.0803729	0.0242062
6 - 11	-0.00343286	0.0250289
10 - 11	*0.0769401	0.0246484

-----

\* denotes a statistically significant difference.



CONCLUSION: The trend in the average BSSOF across the fuels is different for mode 10 at the CA and DF-2 fuels. The trends in the average BSSOF across the fuels for modes 5, 6, and 11 do not appear to be different.

Multifactor ANOVA - BSNOX (g/kW-hr)  
LPP Only Modes 5,6,10,11

#### Analysis Summary

Dependent variable: BSNOX

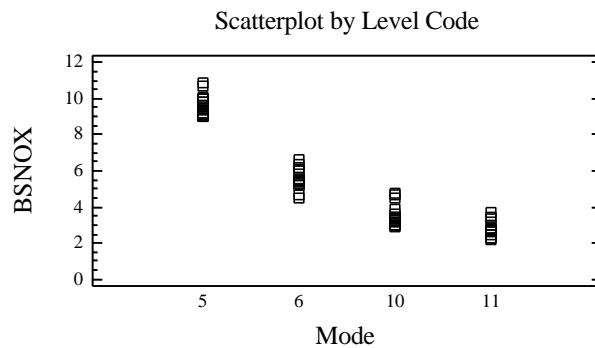
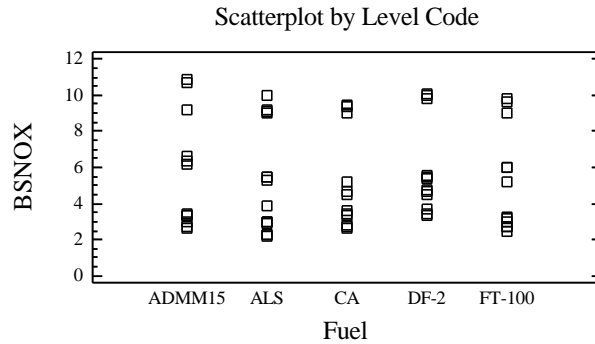
Factors:

FUEL

MODE

Selection variable: MODE<12

Number of complete cases: 62

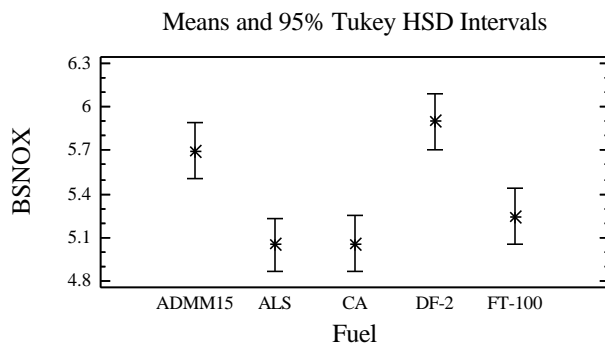


#### Analysis of Variance for BSNOX - Type III Sums of Squares

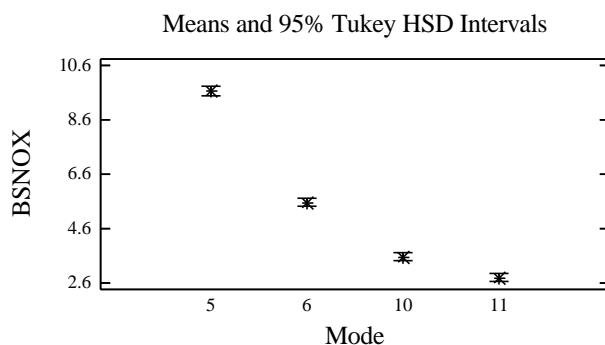
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	7.45754	4	1.86438	16.79	0.0000
B:MODE	443.319	3	147.773	1330.52	0.0000
INTERACTIONS					
AB	6.14855	12	0.512379	4.61	0.0001
RESIDUAL	4.66468	42	0.111064		
TOTAL (CORRECTED)	464.749	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average BSNOX among the fuels, modes, and fuel\*mode interaction.



CONCLUSION: There are two distinct fuel groupings with respect to the average BSNOX. ADMM15 and DF-2 fuels are not significantly different from one another, but are different from the average BSNOX for the ALS, CA, and FT-100 fuels. The ALS, CA, and FT-100 fuels are not significantly different from one another.



CONCLUSION: All four modes are significantly different from one another with respect to the average BSNOX.

#### Multiple Range Tests for BSNOX by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
ALS	14	5.04671	X
CA	12	5.05677	X
FT-100	12	5.24116	X
ADMM15	12	5.69599	X
DF-2	12	5.9005	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	*0.649278	0.373652
ADMM15 - CA	*0.63922	0.387757
ADMM15 - DF-2	-0.204506	0.387757
ADMM15 - FT-100	*0.45483	0.387757
ALS - CA	-0.0100577	0.373652
ALS - DF-2	*-0.853784	0.373652
ALS - FT-100	-0.194448	0.373652
CA - DF-2	*-0.843726	0.387757
CA - FT-100	-0.184391	0.387757
DF-2 - FT-100	*0.659336	0.387757

\* denotes a statistically significant difference.

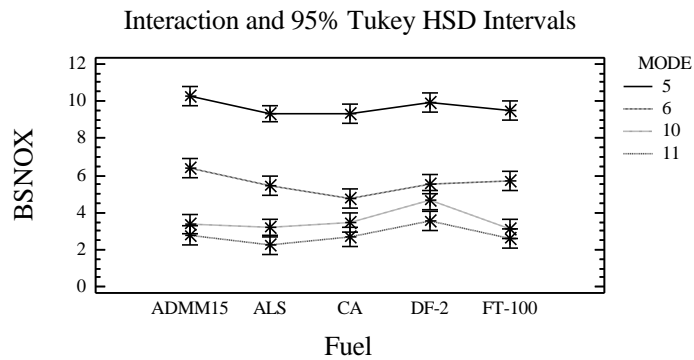
#### Multiple Range Tests for BSNOX by MODE

Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
11	15	2.77949	X
10	16	3.55572	X
6	15	5.55988	X
5	16	9.65782	X

Contrast	Difference	+/- Limits
5 - 6	*4.09794	0.32042
5 - 10	*6.1021	0.315209
5 - 11	*6.87832	0.32042
6 - 10	*2.00416	0.32042
6 - 11	*2.78039	0.325547
10 - 11	*0.776228	0.32042

\* denotes a statistically significant difference.



CONCLUSION: While the ADMM15, ALS, CA, and FT-100 fuels all have significant differences in the average BSNOX between mode 6 and modes 10 and 11, the DF-2 fuel does not demonstrate this difference. The average BSNOX among modes 6, 10, and 11 for the DF-2 are not significantly different from one another.

Multifactor ANOVA - BSHC (g/kW-hr)  
 LPP Only Modes 5,6,10,11

# Analysis Summary

Dependent variable: BSHC

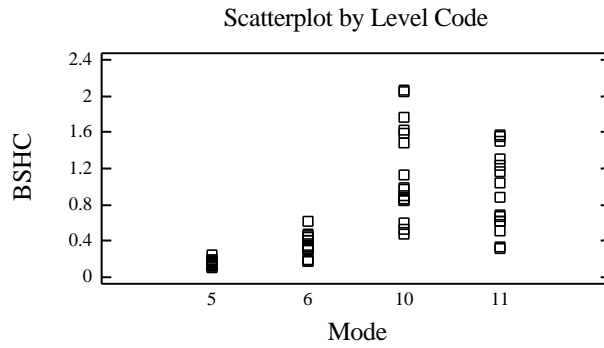
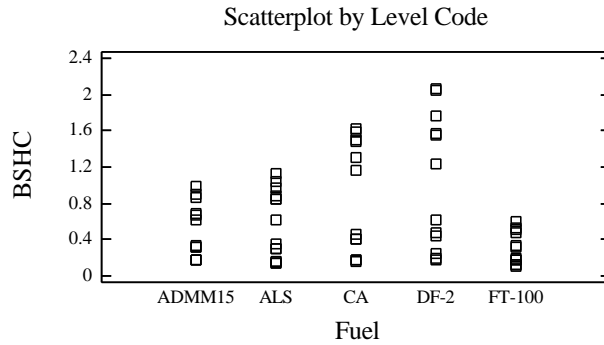
Factors:

FUEL

MODE

Selection variable: MODE<12

Number of complete cases: 62

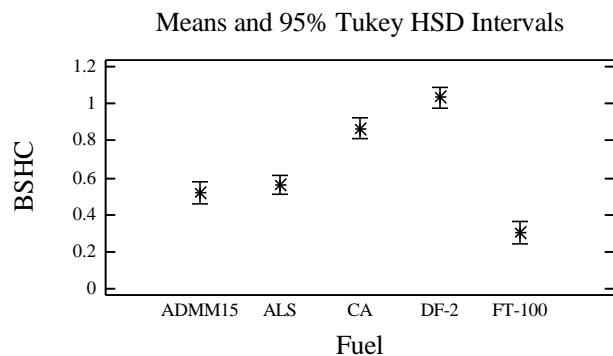


## Analysis of Variance for BSHC - Type III Sums of Squares

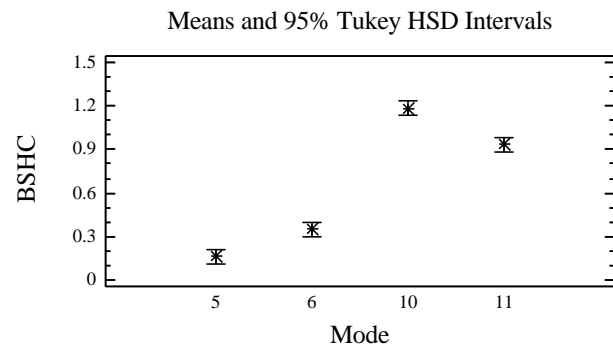
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	4.05731	4	1.01433	104.34	0.0000
B:MODE	10.9203	3	3.64011	374.43	0.0000
INTERACTIONS					
AB	2.4476	12	0.203967	20.98	0.0000
RESIDUAL	0.408308	42	0.00972163		
TOTAL (CORRECTED)	17.7211	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average BSHC among the fuels, modes, and the fuel\*mode interaction.



CONCLUSION: There are four distinct fuel groupings with respect to the average BSHC. FT-100, CA, and DF-2 fuels are all significantly different from one another. Also, fuels ADMM15 and ALS are not significantly different from one another, but they are both significantly different from the other three fuels.



CONCLUSION: All four modes are significantly different from one another with respect to the average BSHC.

#### Multiple Range Tests for BSHC by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	0.302624	X
ADMM15	12	0.519087	X
ALS	14	0.562475	X
CA	12	0.866077	X
DF-2	12	1.03069	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.0433876	0.110548
ADMM15 - CA	*-0.346989	0.114721
ADMM15 - DF-2	*-0.5116	0.114721
ADMM15 - FT-100	*0.216463	0.114721
ALS - CA	*-0.303602	0.110548
ALS - DF-2	*-0.468212	0.110548
ALS - FT-100	*0.259851	0.110548
CA - DF-2	*-0.16461	0.114721
CA - FT-100	*0.563453	0.114721
DF-2 - FT-100	*0.728063	0.114721

\* denotes a statistically significant difference.

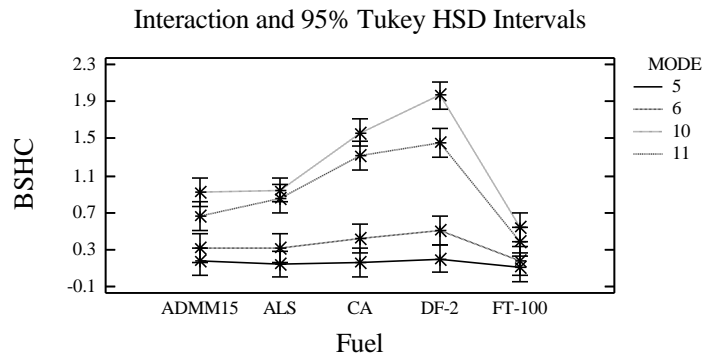
#### Multiple Range Tests for BSHC by MODE

Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
5	16	0.158889	X
6	15	0.346341	X
11	15	0.934782	X
10	16	1.18475	X

Contrast	Difference	+/- Limits
5 - 6	*-0.187453	0.0947987
5 - 10	*-1.02586	0.0932572
5 - 11	*-0.775893	0.0947987
6 - 10	*-0.838407	0.0947987
6 - 11	*-0.58844	0.0963156
10 - 11	*0.249966	0.0947987

\* denotes a statistically significant difference.



CONCLUSION: The ALS, CA, DF-2 fuels have significantly different average BSHC at modes 10 and 11 than at modes 5 and 6. All other fuels do not demonstrate significant differences in the average BSHC among the four modes.

Multifactor ANOVA - BSCO (g/kW-hr)  
LPP Only Modes 5,6,10,11

#### Analysis Summary

Dependent variable: BSCO

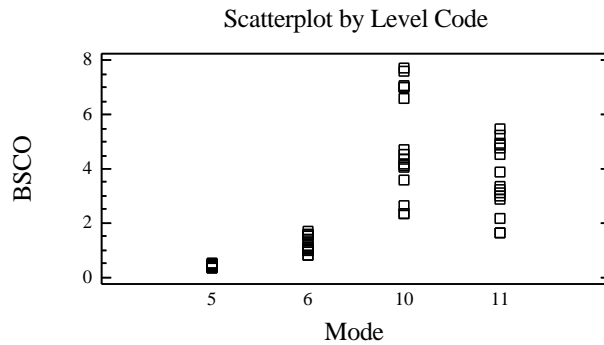
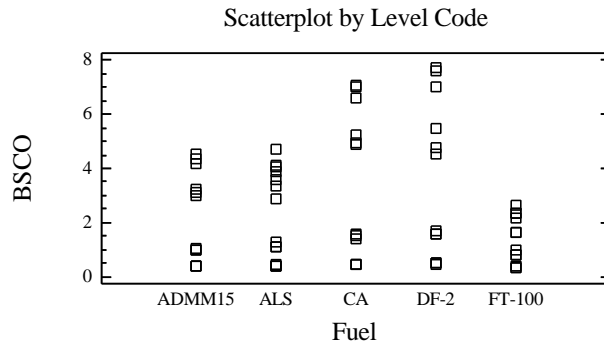
Factors:

FUEL

MODE

Selection variable: MODE<12

Number of complete cases: 62

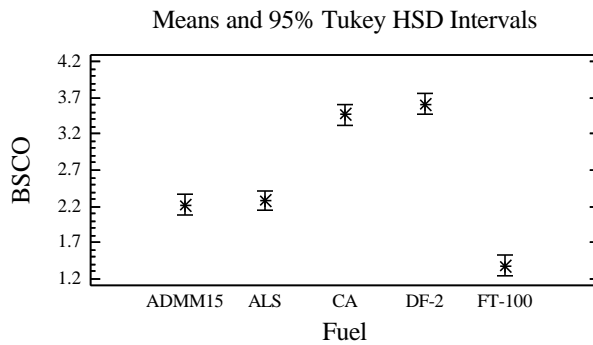


#### Analysis of Variance for BSCO - Type III Sums of Squares

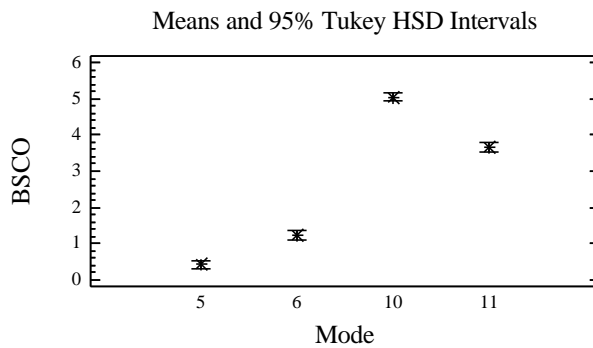
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	42.4521	4	10.613	178.05	0.0000
B:MODE	214.449	3	71.4832	1199.21	0.0000
INTERACTIONS					
AB	33.0659	12	2.7555	46.23	0.0000
RESIDUAL	2.50355	42	0.0596084		
TOTAL (CORRECTED)	290.354	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average BSCO among the fuels, modes, and fuel\*mode interaction.



CONCLUSION: There are three distinct fuel groupings with respect to the average BSCO. FT-100 is significantly different from the other four fuels. ADMM15 and ALS are not significantly different from one another. Fuels CA and DF-2 are not significantly different from one another, but are significantly different from the ADMM15 and ALS fuels.



CONCLUSION: All four modes are significantly different from one another with respect to the average BSCO.

#### Multiple Range Tests for BSCO by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	1.38081	X
ADMM15	12	2.21783	X
ALS	14	2.27253	X
CA	12	3.46699	X
DF-2	12	3.61618	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-0.0547025	0.273738
ADMM15 - CA	*-1.24916	0.284071
ADMM15 - DF-2	*-1.39835	0.284071
ADMM15 - FT-100	*0.837021	0.284071
ALS - CA	*-1.19446	0.273738
ALS - DF-2	*-1.34365	0.273738
ALS - FT-100	*0.891724	0.273738
CA - DF-2	-0.149189	0.284071
CA - FT-100	*2.08618	0.284071
DF-2 - FT-100	*2.23537	0.284071

\* denotes a statistically significant difference.

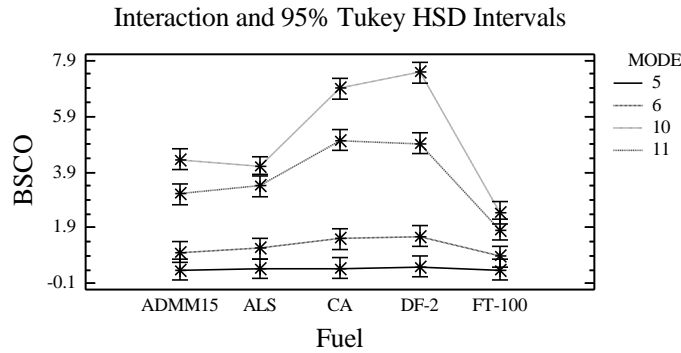
# Multiple Range Tests for BSCO by MODE

Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
5	16	0.426311	X
6	15	1.22936	X
11	15	3.65545	X
10	16	5.05234	X

Contrast	Difference	+/- Limits
5 - 6	*-0.803049	0.23474
5 - 10	*-4.62603	0.230923
5 - 11	*-3.22914	0.23474
6 - 10	*-3.82299	0.23474
6 - 11	*-2.42609	0.238496
10 - 11	*1.3969	0.23474

\* denotes a statistically significant difference.



CONCLUSION: The CA, DF-2, and FT-100 fuels have significantly different average BSCO at modes 10 and 11 than at modes 5 and 6.

Multifactor ANOVA - BSC02 (g/kW-hr)  
LPP Only Modes 5,6,10,11

#### Analysis Summary

Dependent variable: BSC02

Factors:

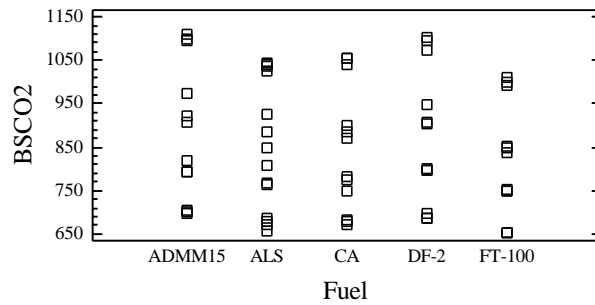
FUEL

MODE

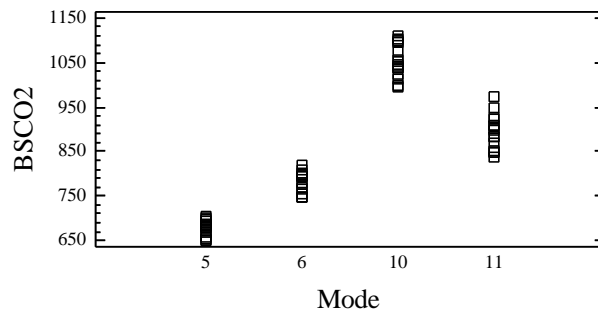
Selection variable: MODE<12

Number of complete cases: 62

Scatterplot by Level Code



Scatterplot by Level Code

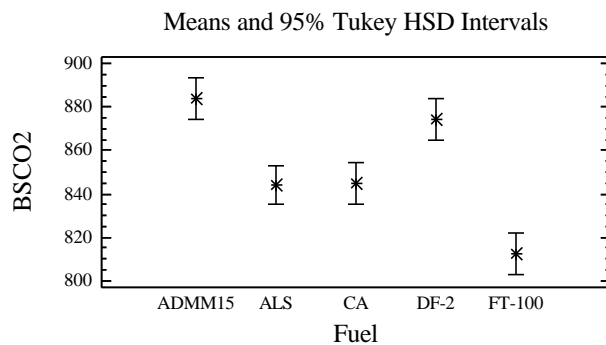


#### Analysis of Variance for BSC02 - Type III Sums of Squares

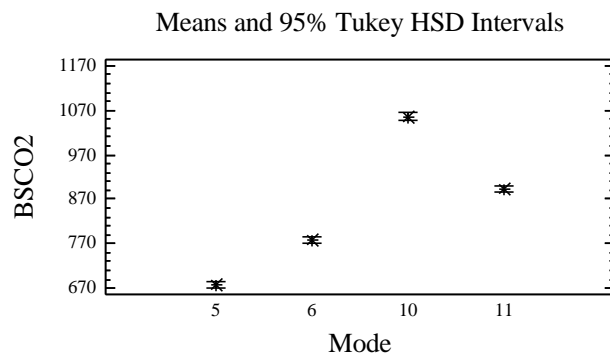
Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	38712.5	4	9678.13	36.18	0.0000
B:MODE	1.23777E6	3	412592.0	1542.24	0.0000
INTERACTIONS					
AB	4961.4	12	413.45	1.55	0.1463
RESIDUAL	11236.1	42	267.527		
TOTAL (CORRECTED)	1.30255E6	61			

All F-ratios are based on the residual mean square error.

CONCLUSION: Statistically significant differences in the average BSC02 among the fuels and the modes.



CONCLUSION: There are three distinct fuel groupings with respect to the average BSC02. FT-100 is significantly different from the other four fuels. ADMM15 and DF-2 fuels are not significantly different from one another. Fuels ALS and CA are not significantly different from one another, but are significantly different from the ADMM15 and DF-2 fuels.



CONCLUSION: All four modes are significantly different from one another with respect to the average BSC02.

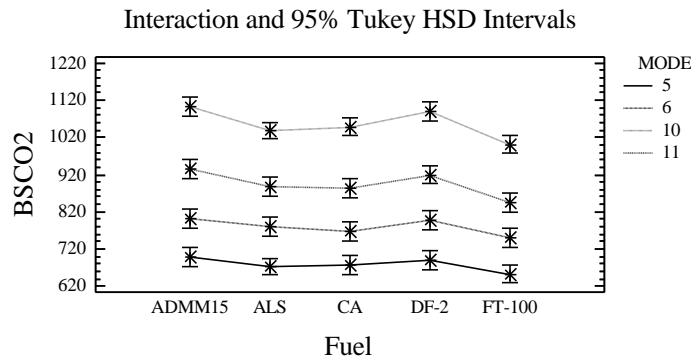
Multiple Range Tests for BSC02 by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
FT-100	12	812.402	X
ALS	14	843.98	X
CA	12	844.665	X
DF-2	12	874.424	X
ADMM15	12	884.069	X
Contrast	Difference		+/- Limits
ADMM15 - ALS	*40.0882		18.3385
ADMM15 - CA	*39.4037		19.0308
ADMM15 - DF-2	9.64418		19.0308
ADMM15 - FT-100	*71.6664		19.0308
ALS - CA	-0.68448		18.3385
ALS - DF-2	*-30.444		18.3385
ALS - FT-100	*31.5783		18.3385
CA - DF-2	*-29.7595		19.0308
CA - FT-100	*32.2628		19.0308
DF-2 - FT-100	*62.0223		19.0308

\* denotes a statistically significant difference.

# Multiple Range Tests for BSC02 by MODE

Method: 95.0 percent Tukey HSD			
MODE	Count	LS Mean	Homogeneous Groups
-----			
5	16	678.385	X
6	15	779.339	X
11	15	894.059	X
10	16	1055.85	X
-----			
Contrast		Difference	+/- Limits
-----			
5 - 6		*-100.954	15.7259
5 - 10		*-377.464	15.4702
5 - 11		*-215.674	15.7259
6 - 10		*-276.51	15.7259
6 - 11		*-114.72	15.9776
10 - 11		*161.79	15.7259
-----			
* denotes a statistically significant difference.			



CONCLUSION: No significant differences among the fuel and mode combinations with respect to the average BSC02.

## Mode 12

Mode 12 is essentially engine idle, and was very difficult to control repeatably. As a result, the variability in engine operation tended to overwhelm any fuel effects. As a result, this mode was excluded from the overall analysis, and treated separately. These analyses are included here for completeness.

Multifactor ANOVA - Total Particulates (g/kW-hr)  
LPP Only Mode 12

#### Analysis Summary

Dependent variable: PARTIC

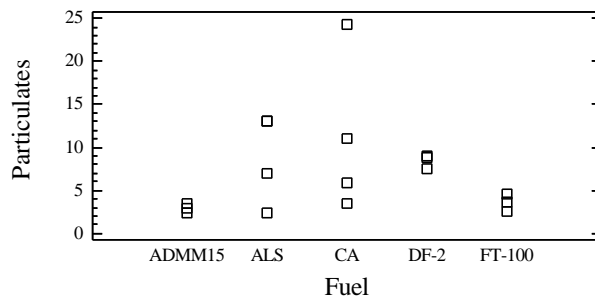
Factors:

FUEL

Selection variable: MODE=12

Number of complete cases: 17

Scatterplot by Level Code



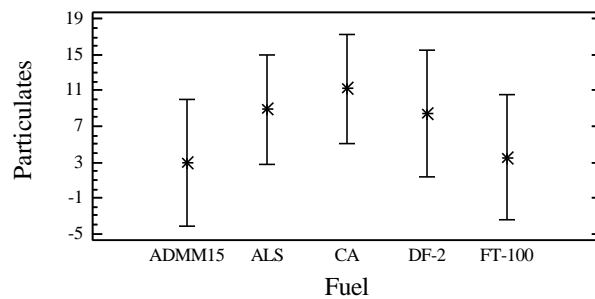
#### Analysis of Variance for PARTIC - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	173.578	4	43.3945	1.50	0.2645
RESIDUAL	348.132	12	29.011		
TOTAL (CORRECTED)	521.71	16			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average particulates among the fuels.

Means and 95% Tukey HSD Intervals



CONCLUSION: No statistically significant differences in the average particulates among the fuels.

#### Multiple Range Tests for PARTIC by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
ADMM15	3	2.90331	X
FT-100	3	3.54611	X

DF-2	3	8.41804	X
ALS	4	8.86013	X
CA	4	11.168	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-5.95682	13.1343
ADMM15 - CA	-8.26472	13.1343
ADMM15 - DF-2	-5.51473	14.0411
ADMM15 - FT-100	-0.642796	14.0411
ALS - CA	-2.3079	12.16
ALS - DF-2	0.44209	13.1343
ALS - FT-100	5.31402	13.1343
CA - DF-2	2.74999	13.1343
CA - FT-100	7.62192	13.1343
DF-2 - FT-100	4.87193	14.0411

\* denotes a statistically significant difference.

Multifactor ANOVA - BSSOF (g/kW-hr)  
LPP Only Mode 12

#### Analysis Summary

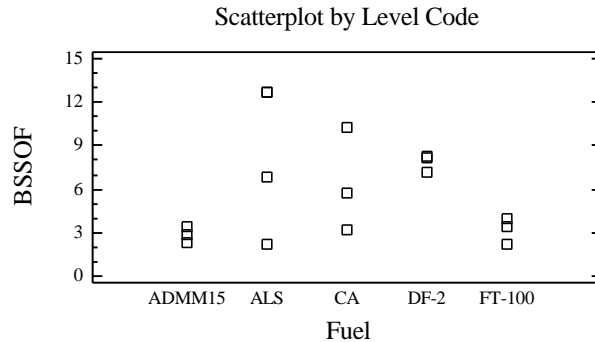
Dependent variable: bssof

Factors:

fuel

Selection variable: mode=12

Number of complete cases: 16

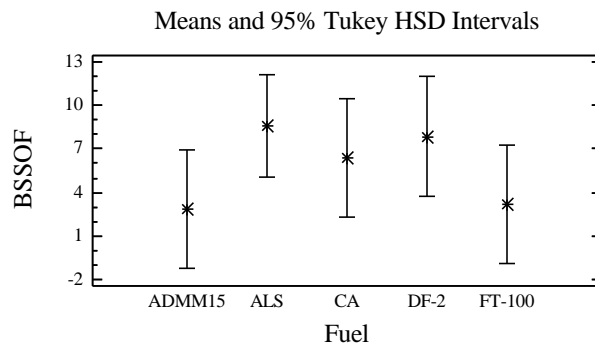


#### Analysis of Variance for bssof - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A: fuel	91.9437	4	22.9859	2.37	0.1165
RESIDUAL	106.826	11	9.71143		
TOTAL (CORRECTED)	198.769	15			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average BSSOF among the fuels.



CONCLUSION: No statistically significant differences in the average BSSOF among the fuels.

#### Multiple Range Tests for bssof by fuel

Method: 95.0 percent Tukey HSD  
fuel                      Count                      LS Mean                      Homogeneous Groups

ADMM15	3	2.83784	X
FT-100	3	3.16754	X
CA	3	6.36478	X
DF-2	3	7.86606	X
ALS	4	8.60195	X
-----			
Contrast	Difference		+/- Limits
-----			
ADMM15 - ALS	-5.76411		7.70442
ADMM15 - CA	-3.52694		8.23638
ADMM15 - DF-2	-5.02821		8.23638
ADMM15 - FT-100	-0.329696		8.23638
ALS - CA	2.23717		7.70442
ALS - DF-2	0.735895		7.70442
ALS - FT-100	5.43441		7.70442
CA - DF-2	-1.50128		8.23638
CA - FT-100	3.19724		8.23638
DF-2 - FT-100	4.69852		8.23638
-----			
* denotes a statistically significant difference.			

Multifactor ANOVA - BSNOX (g/kW-hr)  
LPP Only Mode 12

#### Analysis Summary

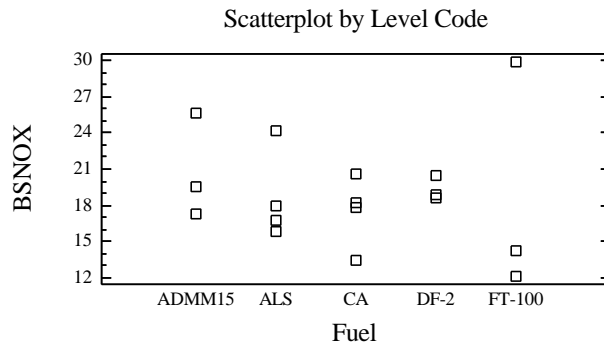
Dependent variable: BSNOX

Factors:

FUEL

Selection variable: MODE=12

Number of complete cases: 17

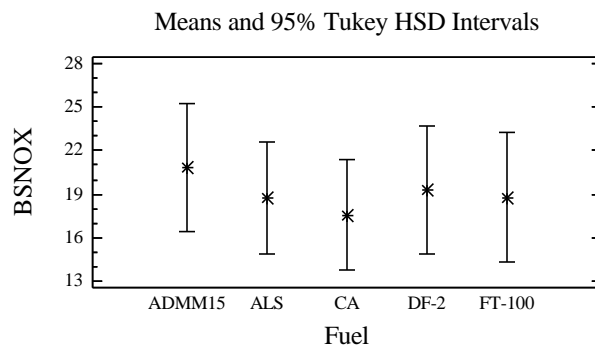


#### Analysis of Variance for BSNOX - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	19.5585	4	4.88963	0.20	0.9353
RESIDUAL	298.211	12	24.8509		
TOTAL (CORRECTED)	317.769	16			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average BSNOX among the fuels.



CONCLUSION: No statistically significant differences in the average BSNOX among the fuels.

#### Multiple Range Tests for BSNOX by FUEL

Method: 95.0 percent Tukey HSD			
FUEL	Count	LS Mean	Homogeneous Groups
CA	4	17.5372	X

ALS	4	18.714	X
FT-100	3	18.7832	X
DF-2	3	19.3197	X
ADMM15	3	20.8529	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	2.13893	12.1561
ADMM15 - CA	3.31568	12.1561
ADMM15 - DF-2	1.53323	12.9955
ADMM15 - FT-100	2.06964	12.9955
ALS - CA	1.17675	11.2544
ALS - DF-2	-0.605695	12.1561
ALS - FT-100	-0.0692861	12.1561
CA - DF-2	-1.78244	12.1561
CA - FT-100	-1.24603	12.1561
DF-2 - FT-100	0.536409	12.9955

\* denotes a statistically significant difference.

Multifactor ANOVA - BSHC (g/kW-hr)  
LPP Only Mode 12

#### Analysis Summary

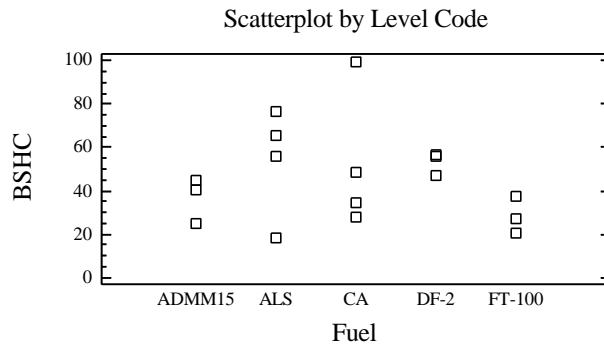
Dependent variable: BSHC

Factors:

FUEL

Selection variable: MODE=12

Number of complete cases: 17

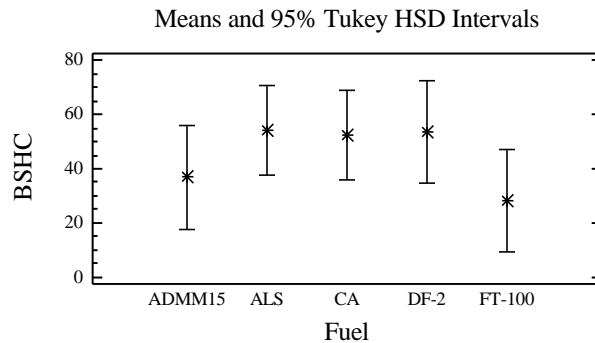


#### Analysis of Variance for BSHC - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	1799.42	4	449.854	0.99	0.4499
RESIDUAL	5456.05	12	454.671		
TOTAL (CORRECTED)	7255.47	16			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average BSHC among the fuels.



CONCLUSION: No statistically significant differences in the average BSHC among the fuels.

#### Multiple Range Tests for BSHC by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
------	-------	---------	--------------------

FT-100	3	28.1695	X
ADMM15	3	36.7632	X
CA	4	52.4152	X
DF-2	3	53.3986	X
ALS	4	54.0764	X
-----			
Contrast	Difference		+/- Limits
-----			
ADMM15 - ALS	-17.3132		51.9964
ADMM15 - CA	-15.652		51.9964
ADMM15 - DF-2	-16.6354		55.5865
ADMM15 - FT-100	8.59372		55.5865
ALS - CA	1.66119		48.1393
ALS - DF-2	0.677775		51.9964
ALS - FT-100	25.9069		51.9964
CA - DF-2	-0.983416		51.9964
CA - FT-100	24.2457		51.9964
DF-2 - FT-100	25.2291		55.5865
-----			
* denotes a statistically significant difference.			

Multifactor ANOVA - BSCO (g/kW-hr)  
LPP Only Mode 12

#### Analysis Summary

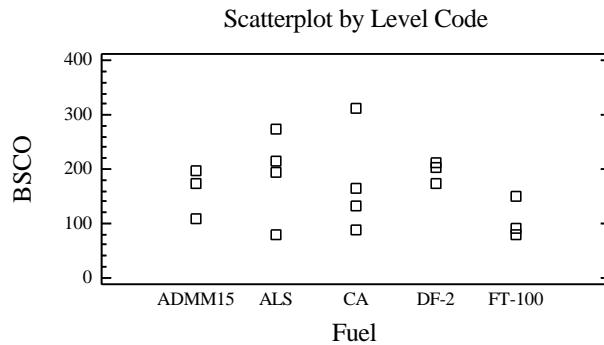
Dependent variable: BSCO

Factors:

FUEL

Selection variable: MODE=12

Number of complete cases: 17

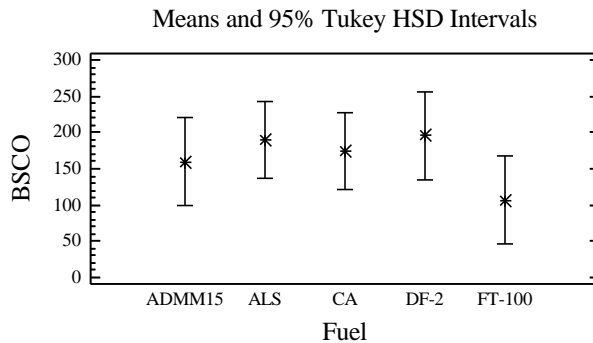


#### Analysis of Variance for BSCO - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	16190.3	4	4047.57	0.86	0.5157
RESIDUAL	56565.5	12	4713.8		
TOTAL (CORRECTED)	72755.8	16			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average BSCO among the fuels.



CONCLUSION: No statistically significant differences in the average BSCO among the fuels.

#### Multiple Range Tests for BSCO by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
FT-100	3	106.035	X
ADMM15	3	159.445	X
CA	4	174.056	X
ALS	4	190.488	X
DF-2	3	195.655	X
Contrast		Difference	+/- Limits
ADMM15 - ALS		-31.0427	167.421
ADMM15 - CA		-14.6106	167.421
ADMM15 - DF-2		-36.2097	178.98
ADMM15 - FT-100		53.4104	178.98
ALS - CA		16.4321	155.002
ALS - DF-2		-5.16696	167.421
ALS - FT-100		84.4531	167.421
CA - DF-2		-21.5991	167.421
CA - FT-100		68.021	167.421
DF-2 - FT-100		89.62	178.98
* denotes a statistically significant difference.			

Multifactor ANOVA - BSC02 (g/kW-hr)  
LPP Only Mode 12

#### Analysis Summary

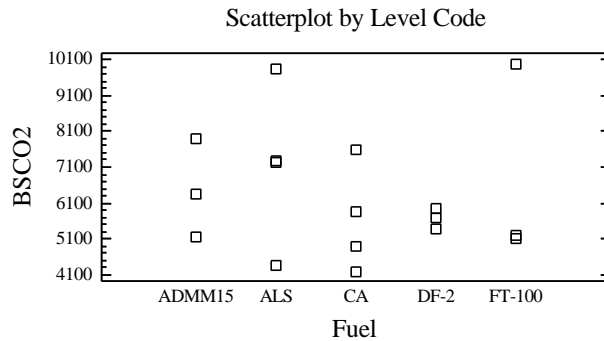
Dependent variable: BSC02

Factors:

FUEL

Selection variable: MODE=12

Number of complete cases: 17

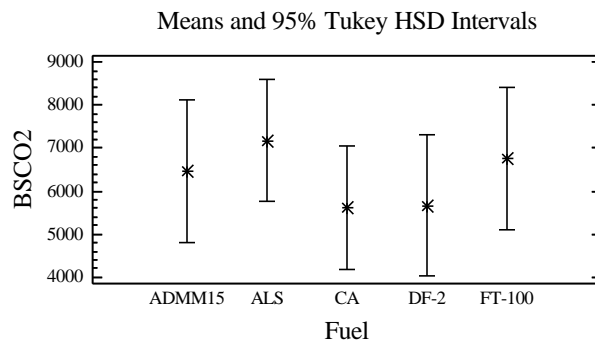


#### Analysis of Variance for BSC02 - Type III Sums of Squares

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
MAIN EFFECTS					
A:FUEL	6.79414E6	4	1.69854E6	0.49	0.7406
RESIDUAL	4.12673E7	12	3.43894E6		
TOTAL (CORRECTED)	4.80614E7	16			

All F-ratios are based on the residual mean square error.

CONCLUSION: No statistically significant differences in the average BSC02 among the fuels.



CONCLUSION: No statistically significant differences in the average BSC02 among the fuels.

#### Multiple Range Tests for BSC02 by FUEL

Method: 95.0 percent Tukey HSD

FUEL	Count	LS Mean	Homogeneous Groups
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CA	4	5618.38	X
DF-2	3	5664.79	X
ADMM15	3	6464.75	X
FT-100	3	6754.19	X
ALS	4	7174.0	X

Contrast	Difference	+/- Limits
ADMM15 - ALS	-709.244	4522.06
ADMM15 - CA	846.375	4522.06
ADMM15 - DF-2	799.964	4834.29
ADMM15 - FT-100	-289.437	4834.29
ALS - CA	1555.62	4186.62
ALS - DF-2	1509.21	4522.06
ALS - FT-100	419.807	4522.06
CA - DF-2	-46.4105	4522.06
CA - FT-100	-1135.81	4522.06
DF-2 - FT-100	-1089.4	4834.29

\* denotes a statistically significant difference.